F.6.3.2 Dry Storage Bounding Accident Scenarios

Three hypothetical accidents were evaluated for foreign research reactor spent nuclear fuel handled in dry storage: (a) fuel element breach (i.e., cutting into the fuel region) or mechanical damage during examination work and handling, (b) dropping of a fuel cask, and (c) an aircraft crash with ensuing fire in the dry storage facility. No credible mechanism was identified for an accident criticality in dry storage.

F.6.4 Bounding Accident Evaluation

F.6.4.1 Basic Assumptions

The analysis of airborne releases from hypothetical accidents is performed using the GENII Version 1.485 computer program. Unless otherwise stated, the following conditions were used when performing calculations. In most cases, these are the default conditions in the GENII program.

Meteorological Data:

- Fiftieth- and 95th-percentile meteorological conditions for each storage site were defined using site-specific joint frequency distribution weather data.
- The release is assumed to occur at ground level (0 m).
- Mixing layer height is 1,000 m (3,280 ft). Airborne materials freely diffuse in the atmosphere near ground level in what is known as the mixing depth. A stable layer exists above the mixing depth which restricts vertical diffusion above 1,000 m.
- Wet deposition is zero (it is assumed that no rain occurs to accelerate deposition and reduce the size of area affected by the release).
- Dry deposition of the cloud is modeled. During movement of the radioactive plume, a fraction of the radioactive material in the plume is deposited on the ground due to gravitational forces. The deposited material no longer contributes to the air immersion dose from the plume, but now contributes as exposure from ground surface radiation and ingestion.
- The quantity of deposited radioactive material is proportional to the material particle size and deposition velocities (in m/sec) used in the GENII code as follows:

solids = 0.001	halogens = 0.01	noble gases = 0.0
cesium = 0.001	ruthenium = 0.001	

- If radioactive releases occur through a stack, then additional plume dispersion can be accounted for by considering the beneficial effects of jet plume rise. In this analysis, jet plume rise is ignored.
- When released gases have a heat content, the plume can disperse more quickly. In this calculation, buoyant plume effects are ignored.

Inhalation Data:

- Breathing rate is 330 cm^3/sec (20.1 in^3/sec) for the worker and the NPAI; 270 cm^3/sec (16.5 in^3/sec) for people at the site boundary and beyond (the MEI and the general population).
- Particle size is 1.0 micro-meter (micron).
- The internal exposure period is 50 years for the individual organs and tissues evaluated.
- Exposure during passage of the entire plume is assessed for the MEI and the general public. Exposures to the worker and NPAI are discussed below.
- Inhalation exposure factors are based on International Commission on Radiological Protection Publication 30 (ICRP, 1979-1982).

Mitigating Factors:

For the MEI and members of the general public residing at the site boundary and beyond, no allowances are made for any preventive or mitigative actions that would limit their exposure. These individuals are assumed to be exposed to the contaminated plume during the entire period of its passage, as it travels downwind from the accident site. Similarly, no action is taken to prevent these people from continuing their normal daily routine, including ingestion of the potentially contaminated terrestrial food and animal products. It is assumed, however, that the public would spend approximately 30 percent (about 8 hours) of the day within their homes or other buildings. Therefore, the exposure of the general public to radiation from contaminated ground surface is reduced appropriately. Calculations were done on a yearly basis to determine the effective annual dosage from inhalation, external exposure, and ingestion, and an associated dose commitment extending over a 50-year period from initiation of intake (NRC, 1977a).

Onsite workers would be trained to take quick, decisive action during an accident. These individuals would be trained to quickly evacuate the affected area and move to well-defined "relocation" areas on the facility. Therefore, it is assumed that workers would be exposed to only 5 minutes of the radioactive plume as they move to relocation centers. Once the plume has moved offsite and downwind, the workers would be instructed to walk to vehicles waiting to evacuate them from the site. It is assumed that an additional 15 minutes would be required to evacuate the workers from the contaminated area and, therefore, the workers would receive a total of 20 minutes of exposure to radioactive material deposited on the ground. No ingestion of contaminated foods is assumed for these individuals.

Individuals that may be traversing the site in a vehicle (i.e., NPAI) would be evacuated from the affected area within 2 hours. This is based on the availability of security personnel at all locations to oversee the removal of collocated workers and travelers in a safe and efficient manner. Therefore collocated workers and travelers would be exposed to the entire contaminated plume as it travels downwind for a period not to exceed 2 hours. Similarly, the radiation from the deposited radioactive materials would be limited to a 2-hour period. No ingestion of contaminated foods is assumed for these individuals.

Table F-105 provides the individual exposure times used in the accident analyses presented later in this appendix.

Table F-105 Estimated Individual Exposure Times

Exposure Type	*Worker (100 m)*	*NPAI*	*MEI/General Public*
To Plume	5 min	100% of release time up to 120 min	100% of release time
To Fallout on Ground Surface	20 min	120 min	0.70 yr
To Food	NA	NA	1 yr

F.6.4.2 Source Term

The source term is the amount of respirable radioactive material, in terms of Ci (curies), that are released to the air. The airborne source term is typically estimated by the following five-component linear equation:

Source Term = MAR x DR x ARF x RF x LPF

where:

MAR = Material-at-Risk (g or Ci),

DR = Damage Ratio,

ARF = Airborne Release Fraction (or Airborne Release Rate for continuous release),

RF = Respirable Fraction, and

LPF = Leak Path Factor.

MAR: The MAR is the amount of radionuclides (in g or Ci of activity for each radionuclide) available to be acted upon by a given physical stress (i.e., an accident). The MAR is specific to a given process in the facility of interest. It is not necessarily the total quantity of material present, but is that amount of material in the scenario of interest postulated to be available for release.

DR: This is the fraction of material exposed to the effects of the energy/force/stress generated by the postulated event. For the bounding accident scenarios discussed in this document, the value of DR is assumed to be one (i.e., all exposed material is released), unless otherwise specified.

ARF: This is the fraction of the material that becomes airborne due to the accident. Generic ARF values from DOE sources (Elder et al., 1986; DOE, 1994d) are used in this document unless other values more appropriate to a particular accident scenario are used for ARF. The values for ARF are summarized in Table F-106.

RF: This is the fraction of the material, with particle sizes of 10 micro-meters (microns) or less (DOE, 1994d) that could be retained in the respiratory system following inhalation. The term RF is applied only for the inhalation pathway.

LPF: The LPF accounts for the action of removal mechanisms, such as containment systems, filtration, deposition, etc., to reduce the amount of airborne radioactivity that is ultimately released to occupied spaces of the facility or to the environment. An LPF of 1.0 (i.e., no reduction) is assigned in accident scenarios involving a major failure of confinement barriers.

Table F-106 Release Fractions[a] for Various Release Mechanisms

Material	*Release Mechanisms*		
	Fuel breach[a]	*Fire*	*Criticality Accident*[b]
Gas			1.0
Noble Gas	1.0	1.0	
Krypton	0.3	1.0	
Other Noble Gas	0.1	1.0	
Halogens	0.1	1.0	0.25[d]
Iodine-129	0.25		
Solids			
Volatile	0.01[c]	2.5×10^{-4} [d,e]	
Nonvolatile	0.01	2.5×10^{-6} [d,e]	

Source: DOE, 1995g

[a] *As recommended in Elder et al., 1986.*

[b] *Regulatory Guide values (NRC, 1977b, 1979b, and 1988b).*

[c] *Actually semi-volatile (cesium, rhodium, antimony, selenium, technetium, and tellurium); review on a case-by-case basis.*

[d] *Includes release fraction, respirable fraction and plate-out.*

[e] *Data from DOE, 1995g.*

F.6.4.3 Description of Radiological Accident Scenarios and Generic Parameters

As discussed previously, the accident screening and selection process led to selection of six bounding accident scenarios involving radioactive materials. Appropriate assumptions also have been discussed regarding meteorological parameters, dispersion parameters, dose estimates, and emergency response and protective actions. Each of the accident scenarios is described in the following text according to the major headings listed below:

- Description of Accident,
- Development of Radioactive Source Term, and
- Dose Calculations and Results.

The contents of these sections and a summary of the generic parameters used follow.

Description of Accident provides a basis for accident selection and discusses possible initiating events. A qualitative assessment of scenario likelihood is provided.

Development of Radioactive Source Term describes the assumptions that apply to the development of the resulting source term. Specifically, it discusses the various multipliers (defined earlier in this section) that convert the MAR to the source term.

These multipliers have the following values:

- DR is 1.0, unless otherwise specified.
- ARF is taken from Table F-106, or clearly stated if different.
- LPF is 1.0 for a major failure of confinement barriers.

Dose Calculations and Results relates the computer modeling to the specific accident scenario, and documents the results. Specifically, these subsections accomplish the following:

- describe assumptions and unique input parameters (other than the source term) used in the computer model,
- document the computer model output in terms of exposure to radionuclides for individuals and for the general population within a 80 km (50 mi) radius, and
- assess the potential for health effects.

Unless otherwise specified, the meteorological/dispersion parameters and estimated exposure times summarized are used in the dosimetry calculations for specific accident scenarios. Under some circumstances, facility worker exposures could be either greater or less than these nominal values.

F.6.4.4 Accident Scenario Descriptions and Source Terms

F.6.4.4.1 Fuel Element Breach

***Description of Conditions*:** Fuel element mechanical damage due to handling during examination, such as accidentally cutting into the fuel region, was assessed. This hypothetical accident results from inadvertent cutting across the fuel region when cropping off the aluminum and nonfuel ends of a fuel unit. All noble gas isotopes are postulated to be released to the facility building and escape to the environment. The majority of the volatile and solid nuclides are likely to be retained in the fuel or the facility exhaust filters. The resulting airborne release to the environment was evaluated.

***Likelihood*:** The frequency of this scenario is estimated to be 0.16/yr (DOE, 1995g). This frequency estimate is based on historical operation data (one event in 6 years) for a spent nuclear fuel storage facility. This estimate is conservative for the case of foreign research reactor spent nuclear fuel storage because the majority of the spent nuclear fuel elements are expected to be cropped prior to their emplacement in a transportation cask at a foreign research reactor. Nevertheless, this estimate is retained for the evaluation of the potential risk associated with the handling and preparation of foreign research reactor spent nuclear fuel for storage in both a dry and a wet storage facility.

***Source Term*:** Conditions used in developing the source term are as follows:

- Only one spent nuclear fuel element is damaged. This is because only one spent nuclear fuel element is being handled at a time.

If the spent nuclear fuel cutting accident occurs in a dry cell (dry storage), the following assumptions apply:

- All (100 percent) of the noble gases available for release are released to the atmosphere. Here, it was assumed that all noble gases in an irradiated fuel element would be released. This is conservative, since foreign research reactor fuels are dispersion fuels in which the gaseous fission products are essentially trapped within the fuel matrix. This is different than for commercial reactor fuel, where gaseous fission products collect in the gap between the fuel and its sealed metal fuel rod and are readily released if the rod is damaged.

- Twenty-five percent of the halogens in the spent nuclear fuel are released to the environment. This is also conservative for the reason stated above.
- One percent of the particulate fission products is released to the dry cell from the spent nuclear fuel element, and 99.9 percent removed prior to release to the environment by the normally installed high-efficiency particulate air filters. The use of 99.9 percent efficiency is conservative, since normal efficiency of installed high-efficiency particulate air filters is greater than 99.99 percent.
- Cesium (Cs) and Ruthenium (Ru) behave like particulate fission products.
- The release to the environment occurs at a constant rate over a 15-minute period.

If the spent nuclear fuel cutting accident occurs under water (wet storage) the following assumptions apply:

- All (100 percent) of the noble gases available for release are released to the environment.
- Twenty-five percent of the halogens available for release will be released to the pool, and only 10 percent of this amount will be released to the air. This additional reduction is due to the fact that halogen gases dissolve in the water as they escape (leak out) from the failed fuel. Based on solubility alone, it is expected that all iodines are dissolved in the water pool before they get to the pool surface. In spite of this fact, for the purposes of the analyses, it was assumed that 2.5 percent of halogens available for release will be released to the atmosphere.
- There is no particulate fission product release to the environment. All particulates are retained in the pool water.
- Since only gaseous fission products are released to the air inside the facility, installed high-efficiency particulate air filters would not provide additional reduction in the amount of material released to the environment.
- The release to the environment occurs at a constant rate over a 15-minute period.

F.6.4.4.2 Accidental Criticality

Description of Conditions: In this hypothetical accident scenario, an accidental uncontrolled chain reaction producing 1×10^{19} fissions is postulated. The 10^{19} fission criticality is a very conservative assumption for the spent nuclear fuel pool. This assumption is only applicable to liquid processes (such as uranium reprocessing) as stated in Regulatory Guides 3.33 and 3.34 (NRC, 1979a and 1979b). This criticality is assumed to consist of an initial burst of 10^{18} fissions in 0.5 seconds, followed at 10 minute intervals for the next 8 hours by a burst of 2×10^{17} fissions, for a total of 10^{19} fissions. The total yield for a moderated solid system, as applicable to the spent nuclear fuel in a wet pool, is estimated to be on the order of 10^{18} fissions. This is because the initial criticality will disrupt the critical geometry and no further criticality burst will occur.

The criticality occurs in the water pool and the spent nuclear fuel remains covered in the water. The fission products released include those specified in Regulatory Guide 3.34 (NRC, 1979b) from the criticality over an 8-hour period, plus fission products existing in the fuel as a result of its original use in the foreign research reactor. Removal of fission products by the pool water is considered in the analysis.

Criticality is not considered in the dry storage because the licensing design basis for spent nuclear fuel dry storage design facilities precludes the consideration of any criticality accident by design. The design must demonstrate, through rigorous structural and criticality analyses, that the likelihood of a criticality is incredible or unforeseeable. No effective moderator, such as water, exists in a dry storage design; and, even if flooded, it remains subcritical.

Likelihood: The frequency of this scenario is estimated at 3.1 x 10^{-3} per year (DOE, 1995g). The estimation of this frequency was conservatively based on a statistical evaluation considering that no accidental criticality event with spent nuclear fuel storage has occurred (DuPont, 1983b). This frequency is estimated by considering both the various process-related upset conditions and the natural phenomena hazard (i.e., earthquake and tornadoes) initiated criticality events. The magnitude of fission yield for such a criticality accident was estimated to range from about 5 x 1017 to 1 x 10^{19} fissions. The historical criticality accidents at different DOE facilities dealing with spent nuclear fuels indicate a much smaller fission yield than that evaluated here. The frequency of an accidental criticality of the magnitude evaluated here is estimated to be between one and two orders of magnitude less than the estimated frequency.

Source Term: Conditions used in developing the source term are as follows:

- The fractions of the fission products from damaged spent nuclear fuel elements released to the building are 100 percent of the noble gases, 25 percent of the halogens, 0.1 percent of the Ru, and 0.05 percent of the Cs and remaining solids (NRC, 1977b, 1979b, and 1988b).
- Fission products from 10 spent nuclear fuel elements damaged in the criticality accident are also released in addition to the gaseous fission products created by the criticality event.
- A high-efficiency particulate air filter removes 99.9 percent of the solid fission products that were released to the air inside the facility before they enter the environment.
- The release to the environment occurs at a constant rate over a 15-minute period. This is conservative as compared to the 8-hour release allowed in Regulatory Guide 3.34 (NRC, 1979b).

F.6.4.4.3 Aircraft Crash

Dry Storage:

Description of Conditions: A hypothetical aircraft accident scenario was developed for the dry storage option. This accident is analyzed only at storage sites that have a likelihood of accident occurrence greater than 10^{-7} per year. The consequences of this accident are expected to bound all other dry storage accident scenarios involving an impact that results in fire. The aircraft crash accident is postulated to cause damage to a single transfer container in the dry unloading cell in a modular vault storage facility. Engineering experience indicates that most of the aircraft structure is stopped by the dry storage building structure. Only a heavy dense jet engine rotor shaft is expected to be capable of penetrating the building and damaging the container. Due to the severity of the impact, it was assumed that the cask is breached and the fuel elements in the cask are damaged. The release of fission products occurs due to the impact and resultant fire (i.e., from aviation fuel).

The accident scenario for a dry cask storage facility is similar to that of a modular vault facility. The aircraft crash analysis is the only accident scenario applicable to a dry cask storage. In this scenario, it is expected that the concrete structure which houses the storage canisters is sufficiently rugged that it can survive an aircraft accident with no significant damage to the spent nuclear fuel.

Likelihood: The frequency of this scenario is site dependent. DOE, as part of the Programmatic SNF&INEL Final EIS, has performed calculations of aircraft crash hit frequencies at potential storage sites (i.e., Savannah River Site, Idaho National Engineering Laboratory, Oak Ridge Reservation, Hanford Site, and Nevada Test Site) for naval fuel (DOE, 1995g). The reported crash frequencies are: 2×10^{-6} per year for the Savannah River Site, 1×10^{-6} per year for the Oak Ridge Reservation, 4×10^{-7} per year for Nevada Test Site, 7×10^{-8} per year for the Idaho National Engineering Laboratory, and 4×10^{-8} per year for the Hanford Site. These frequency estimates were based on the number of commercial air carriers and military aircraft passing within a 10-mile radius of the proposed storage location at these sites. The calculations for the Idaho National Engineering Laboratory also included potential hazards from a nearby airport. These calculations were performed very conservatively, by considering that all the overflights within the 10-mile radius will pass directly over the storage location at each site.

A new assessment of aircraft impact probabilities for the Idaho National Engineering Laboratory chemical processing plant indicates a frequency of aircraft crash into a dry storage facility the size of the IFSF of about 2.6×10^{-10} per year from overflights and 3.5×10^{-7} per year from airport-related flights near the plant (WINCO, 1994). (The IFSF effective area is five times that considered in the evaluation for the naval fuel storage area, which represents the critical areas containing spent nuclear fuel. Therefore both results are consistent, from the overall crash frequency point of view at the Idaho National Engineering Laboratory.)

In order to provide an understanding of the rationale used in this EIS for this scenario, an overview of the aircraft crash analysis approach is presented. In general, the aircraft crash hit frequency is calculated based on four factors: number of flight operations (takeoff, landing, overflight), aircraft crash rate, facility effective area, and an assumption of crash area distribution. Several models are currently used to estimate the hit frequency. The results of these models are driven by the assumptions regarding the target area and crash area distribution. For example, assuming that overflights (high or low altitude) pass over the facility inherently assumes that the crash area distribution is a straight line. This overestimates the frequency by at least a factor of 10 (approximate width of an airway). In calculating effective area, the analysis considers that an aircraft can hit a facility either directly (falling on the building, footprint area), by skidding into the building (skid area), or in an angular impact (shadow area). Depending on the assumptions of skid length and the angular approach of a crash terminating aircraft, the sum of the latter two areas may contribute between 80 to 95 percent of the total effective area. It is important to note that aircraft that fall vertically with the greatest impact contribute between 1 and 10 percent to the overall crash rate. Therefore, for the majority of cases, the aircraft will hit the ground before it hits the facility.

Based on the above summary, it is considered that frequencies reported in the Programmatic SNF&INEL Final EIS are conservative by at least a factor of 10 for all sites except the Idaho National Engineering Laboratory. Nonetheless, for the purposes of analyses and consistency, this EIS will consider frequencies similar to those used in the Programmatic SNF&INEL Final EIS. The potential aircraft crash frequency at the Oak Ridge Reservation, the Nevada Test Site, the Idaho National Engineering Laboratory, and the Savannah River Site is conservatively set at 10^{-6} per year. This scenario will not be applicable to the Hanford Site, where the estimated frequency is less than 10^{-7} per year.

Source Term: Conditions used in developing the source term are as follows:

- Only one transfer cask containing 20 spent nuclear fuel elements would be damaged by the impact and the resultant fire. This is based on the fact that, if an aircraft hits the building, only the transfer cask is susceptible to damage by the crash. The stored casks are protected by a three-foot concrete shield, and therefore would not be affected by the crash. Based on a conservative estimate of the duration of the transfer operation, the transfer cask could be damaged by the accident only one percent of the time.

- Of the available fission products, 100 percent of the noble gases, 100 percent of the halogens, 2.5 percent of the cesium, and 0.025 percent of the remaining solids are released to the environment. The overall, respirable fractions of fission products released to the environment are consistent with that given in Table F-106 for a fire scenario.

- The release to the environment occurs at a constant rate over a 15-minute period.

- No filtration by high-efficiency particulate air filters is assumed.

For dry cask storage, it was assumed that the ruggedness of the overall dry cask structure is similar to that of a transportation cask. Based on this assumption, the accident source terms were assumed to be similar to that of aluminum-based spent nuclear fuel source terms for the highest severity accident (cask damage and fire) utilized in the RADTRAN accident analysis (DOE, 1995g). The overall source terms for this scenario include: 63 percent of noble gases, 6×10^{-3} percent of halogens, 1×10^{-3} percent of cesium, 2.4×10^{-4} percent of ruthenium, and 1×10^{-5} percent of other solid fission products available in a dry cask.

Wet Storage:

***Description of Conditions*:** Impact into water pools by aircraft with resulting damage to the spent nuclear fuel elements stored inside the pool was evaluated. The hypothetical accident might damage the fuel either by the aircraft directly striking it or by the aircraft causing sufficient damage to the building to cause part of the building to collapse and strike the fuel. Fission products are released from the spent nuclear fuel units into the water pool, however, the pool water is not released to the environment. An aircraft crash into a water pool would not produce enough force to cause the pool to leak because the walls of the water pool are constructed of thick reinforced concrete with earth surrounding them, making them very strong. In addition, based on the discussion provided above, it was judged unlikely that an aircraft would impact the water pool at an angle steep enough to expose the floor of the pool or the walls of the pool below the water level to direct impact.

***Likelihood*:** The same frequency as discussed above will be used for an aircraft crash into a wet storage facility.

***Source Term*:** Conditions used in developing the source term are as follows:

- It was estimated that about 140 spent nuclear fuel elements would damaged. This estimate was based on the consideration of the size of spent nuclear fuel allowing fuel stacking and an assumption that only one percent of the upper stacked fuel will be damaged.

- Of the available fission products, 100 percent of the noble gases and 25 percent of the halogens are released to the pool water. Due to the presence of pool water, a reduction of the halogen release by a factor of 10 occurs prior to release to the environment.

- The pool water is not expected to be lost and the solid fission products from ruptured and damaged fuel elements remain in the water. However, for the purposes of this analysis, it was conservatively assumed that 0.01 percent of the solid fission products (including Cs and Ru) released from the damaged fuel elements to the pool would be displaced upon impact. Only one percent of released solid fission products would become airborne and released to the environment. This assumption considers that, upon impact, a percentage of the spent nuclear fuel fails, the solid fission products enter the pool, and only finely crushed particulates are splashed out of the pool in the same timeframe that the aircraft hits the water.

- The release to the environment occurs at a constant rate over a 15-minute period.
- Spent nuclear fuel elements remained covered in the water pool.
- The building confinement is assumed to have failed; no filtration by high-efficiency particulate air filters is assumed.

F.6.4.4.4 Fuel Cask Drop

Dry Storage:

Description of Conditions: Mechanical damage due to handling during examination, such as dropping of the spent nuclear fuel cask during transfer, was assessed. The fuel casks are certified to result in no failure for a specific drop height, (free drop from 9 m [30 ft] height onto an unyielding surface), and under no circumstances will the cask be moved above such height during operations within a storage facility. Nevertheless, it was assumed that, upon cask drop, the seals of the cask would fail, releasing the gaseous fission products from the damaged fuel inside the cask to the facility building and the environment. All of the nonvolatile and solid nuclides are assumed to be retained in the fuel or the facility high-efficiency particulate air filters. The resulting airborne release to the environment was evaluated.

Likelihood: The frequency of this scenario is estimated at 10^{-4} per year (DOE, 1995g). This estimate is considered to be an upper bound for this scenario.

Source Term: Conditions used in developing the source term are as follows:

- Only one fuel cask is involved. This is because only one fuel cask is being handled at a time. For the purposes of this analysis, it was assumed that an equivalent of one spent nuclear fuel element inside the cask is damaged, and its gaseous fission products are released inside the cask. This assumption is conservative, since the fuel is secured inside the cask and the cask is not expected to be damaged.
- All (100 percent) of the gaseous fission products and 25 percent of halogens from the damaged fuel element are released to the atmosphere.
- None of the particulate fission products are released to the environment.
- Cs and Ru behave like particulate fission products.
- The release to the environment occurs at a constant rate over a 15-minute period.

Wet Storage:

The source term for a fuel cask drop is similar to that for the fuel element breach scenario in a wet storage facility. The gaseous fission products released inside the cask are vented under water (or in the pool). Since the estimated frequency of this scenario is less than that of the fuel element breach, no specific analysis for this scenario was performed.

F.6.5 Incident-Free Operation Source Terms

This section details the assumptions and the evaluation process used to determine the risk of radiological emissions generated during different activities in incident-free operation of a storage facility. The incident-free operation emissions consist of two parts: transient (i.e., emissions from gaseous release during receipt and unloading of the transportation casks), and steady state (i.e., emissions from spent nuclear fuel in storage). Since only mechanically sound spent nuclear fuel elements are shipped, no radioactive releases are expected during transit. To ensure this, the spent nuclear fuel elements are checked prior to shipment to identify and separate any damaged fuel elements. The damaged fuel elements are then encapsulated and prepared for shipment. In spite of the fact that no spent nuclear fuel elements have ever failed during transit, it was assumed that one percent of the spent nuclear fuel elements will arrive failed and release gaseous fission products (noble gases and halogens) into the cask. Depending on the type of storage facility, the receipt and unloading of the transportation casks could occur in a dry cell or a wet pool. Unloading operations in a dry cell causes all gaseous fission products to be released to the building and eventually to the environment. If the unloading process occurs in a wet pool, a majority of the halogen gases will be absorbed in the water; only 10 percent of halogens will be released to the environment. The building high-efficiency particulate air filters will not be effective for halogens and noble gases. During the unloading process, all spent nuclear fuel elements are checked to ensure that they are mechanically sound. If a damaged fuel element is found, it is encapsulated in a can before it is placed in wet or dry storage. The potential annual radiological releases from failed fuel elements during the unloading process were estimated based on the gaseous inventories of bounding fuels (see Appendix B, Section B.1.4) ad the associated number of fuels expected over the acceptance period. The receipt and unloading process of foreign research reactor spent nuclear fuel from abroad is expected to last 13 years (see Section 2.2.1). It was assumed that failed fuel would release 100 percent of its noble gases and 25 percent of its halogens. This assumption is consistent with that used in the accident analysis.

The steady state emissions from a new wet storage facility are assumed to be similar to those released from the RBOF facility at the Savannah River Site. Although the emissions at the RBOF facility may not be a good representation of the foreign research reactor spent nuclear fuel, RBOF has the most foreign research reactor spent nuclear fuel elements stored in its pool; and as such, was considered to provide the best approximation of the expected release. Based on the emission data from RBOF, the steady-state emissions from a wet storage facility are assumed to be about 2×10^{-7} curies of Cesium-137 per year (DOE, 1995g). This is a conservative assumption. For existing wet storage facilities, the radiation exposure to the MEI and the general public were estimated based on the combined radionuclide atmospheric emissions originating from current conditions of the facilities and that expected from foreign research reactor spent nuclear fuel. At Savannah River Site, the average annual atmospheric emissions from the existing fuels at L-reactor disassembly basin are estimated to be 254 curies of tritium and 6.49×10^{-5} curies of Cesium-137 (Shedrow, 1994b) over Phase 1 of the policy period. The assumption is that the foreign research reactor spent nuclear fuel would be stored temporarily (about 10 years) in the wet pool until a more permanent dry storage facility is built. The annual atmospheric radiological emissions from RBOF and BNFP wet pools are similar to those that are currently released from RBOF and which were used for a new facility. The annual atmospheric radiological emissions from the Idaho National Laboratory's FAST wet storage facility were assumed to be similar to that of a new wet storage facility. This facility has been designed and built according to current codes and regulations.

The steady-state emissions from a dry storage facility are considered to be zero. This is because the fuel will be checked to ensure that it is mechanically sound (i.e., no damage) before it is placed into dry storage, and the dry storage canisters that house the fuel are sealed.

F.6.6 Dose Calculations and Results

F.6.6.1 Source Terms

Tables F-107 and F-108 provide the incident-free operation and accident source terms. The source terms for the annual emissions from the unloading process were calculated based on the assumption that a constant annual rate of fuel mix with bounding radionuclide inventories (as defined in Appendix B, Section B.1) is received over the acceptance period. The fission products in a BR-2 type spent nuclear fuel element were used as the MAR in the accident analysis source term calculations (see Appendix B for more details). Four fuel categories were defined in Appendix B: BR-2, NRU, RHF, and TRIGA. BR-2 fuel type constitutes the majority of the foreign research reactor spent nuclear fuels. In addition, since spent nuclear fuels come in different sizes and lengths, use of the BR-2 spent nuclear fuel in the accident analysis means involvement of a larger number of spent nuclear fuels in each accident. For example, in the source term calculations for an aircraft crash accident involving a transfer cask, it was assumed that the cask would contain 20 BR-2 spent nuclear fuel elements. If the cask contained NRU elements, there would be five elements in the cask; and if it contained RHF elements, there would be only four elements per cask. For the generic wet storage case, the bounding spent nuclear fuel is considered to have been cooled at least 300 days prior to shipment. In the case of dry storage, the fuel has been cooled for at least 3 years.

Table F-107 Annual Emission Releases From Storage Facilities

	Releases During Unloading in		*Steady State*	
Isotope	*Dry Cell (Ci)*	*Wet Pool (Ci)*	*Dry Storage (Ci)*	*Wet Storage (Ci)*
Tritium	39.6	39.6	---	---
Krypton-85	1.14×10^{3}	1.14×10^{3}	---	---
Iodine-129	4.87×10^{-4}	4.87×10^{-5}	---	---
Iodine-131	9.12×10^{-4}	9.12×10^{-5}	---	---
Xenon-131	2.01×10^{-5}	2.01×10^{-5}	---	---
Cesium-137	---	---	0.0	2.20×10^{-7}

Table F-108 Accident Source Terms (Curies)

	Dry Storage[a]			*Wet Storage*		
Isotope	*Fuel Element Breach*	*Dropped Fuel Cask*	*Aircraft Crash with Fire*	*Accident Criticality*[b]	*Fuel Element Breach*	*Aircraft Crash*
Tritium	2.40	2.12	42.4	24.0	2.40	336
Krypton 85	68.6	59.7	1,190	686	68.6	9,610
Iodine 129	3.04×10^{-5}	2.93×10^{-5}	2.34×10^{-3}	3.04×10^{-4}	3.04×10^{-6}	4.26×10^{-4}
Iodine 131	8.88×10^{-8}		0.0	2.20	8.88×10^{-9}	1.24×10^{-6}
Xenon 131m	3.71×10^{-5}		0.0	8.24×10^{-2}	3.71×10^{-5}	5.19×10^{-3}
Strontium 89	1.13×10^{-2}		1.42×10^{-6}	5.67×10^{-3}		0.159
Strontium 90	5.78×10^{-3}		2.73×10^{-2}	2.89×10^{-3}		8.09×10^{-2}
Yttrium 90	5.78×10^{-3}		2.73×10^{-2}	2.89×10^{-3}		8.09×10^{-2}
Yttrium 91	2.03×10^{-2}		8.35×10^{-6}	1.01×10^{-2}		0.284
Zirconium 95	2.97×10^{-2}		3.31×10^{-5}	1.49×10^{-2}		0.416
Niobium 95	6.11×10^{-2}		7.15×10^{-5}	3.06×10^{-2}		0.856
Ruthenium 103	2.47×10^{-3}		1.12×10^{-8}	2.47×10^{-3}		3.46×10^{-2}
Rhodium 103m	2.47×10^{-3}		1.12×10^{-8}	2.47×10^{-3}		3.46×10^{-2}

	Dry Storage[a]			Wet Storage		
Isotope	Fuel Element Breach	Dropped Fuel Cask	Aircraft Crash with Fire	Accident Criticality[b]	Fuel Element Breach	Aircraft Crash
Ruthenium 106	5.97×10^{-3}		6.70×10^{-3}	5.97×10^{-3}		8.36×10^{-2}
Rhodium 106m	5.97×10^{-3}		6.70×10^{-3}	5.97×10^{-3}		8.36×10^{-2}
Tin 123	1.19×10^{-4}		8.30×10^{-6}	5.93×10^{-5}		1.66×10^{-3}
Antimony 125	2.47×10^{-4}		7.10×10^{-4}	1.24×10^{-4}		3.46×10^{-3}
Tellurium 125m	5.89×10^{-5}		1.74×10^{-4}	2.94×10^{-5}		8.24×10^{-4}
Tellurium 127m	2.46×10^{-4}		1.55×10^{-5}	1.23×10^{-4}		3.45×10^{-3}
Tellurium 129m	5.25×10^{-5}		2.95×10^{-11}	2.63×10^{-5}		7.35×10^{-4}
Cesium 134	4.56×10^{-3}		1.10	2.28×10^{-3}		6.38×10^{-2}
Cesium 137	5.72×10^{-3}		2.73	2.86×10^{-3}		8.01×10^{-2}
Cerium 141	1.59×10^{-3}		3.53×10^{-10}	7.97×10^{-4}		2.23×10^{-2}
Cerium 144	8.67×10^{-2}		6.25×10^{-2}	4.33×10^{-2}		1.21
Praseodymium 144	8.67×10^{-2}		6.25×10^{-2}	4.33×10^{-2}		1.21
Promethium 147	1.34×10^{-2}		3.78×10^{-2}	6.71×10^{-3}		0.188
Promethium 148m	2.10×10^{-5}		1.70×10^{-10}	1.05×10^{-5}		2.94×10^{-4}
Europium 154	1.72×10^{-4}		7.30×10^{-4}	8.61×10^{-5}		2.41×10^{-3}
Europium 155	3.61×10^{-5}		1.32×10^{-3}	1.81×10^{-5}		5.06×10^{-4}
Uranium 234	2.50×10^{-10}		1.80×10^{-9}	1.27×10^{-10}		3.55×10^{-9}
Uranium 235	3.80×10^{-9}		1.90×10^{-8}	1.90×10^{-9}		5.37×10^{-8}
Uranium 238	9.50×10^{-11}		4.70×10^{-10}	4.70×10^{-11}		1.33×10^{-9}
Plutonium 238	1.78×10^{-5}		8.75×10^{-5}	8.92×10^{-6}		2.50×10^{-4}
Plutonium 239	5.11×10^{-7}		2.57×10^{-6}	2.56×10^{-7}		7.16×10^{-6}
Plutonium 240	3.33×10^{-7}		1.68×10^{-6}	1.67×10^{-7}		4.67×10^{-6}
Plutonium 241	7.89×10^{-5}		3.56×10^{-4}	3.94×10^{-5}		1.10×10^{-3}
Americium 241	1.10×10^{-7}		1.85×10^{-6}	5.50×10^{-8}		1.54×10^{-6}
Americium 242m	2.92×10^{-10}		1.44×10^{-9}	1.46×10^{-10}		4.08×10^{-9}
Americium 243	1.20×10^{-9}		6.00×10^{-9}	6.01×10^{-10}		1.68×10^{-8}
Curium 244	3.69×10^{-7}		2.25×10^{-7}	1.85×10^{-7}		5.17×10^{-6}
Curium 242	4.86×10^{-7}		6.40×10^{-8}	2.43×10^{-7}		6.81×10^{-6}
Krypton 83m				160		
Krypton 85m				150		
Krypton 87				990		
Krypton 88				650		
Krypton 89				42,000		
Xenon 133m				1.80		
Xenon 133				27.0		
Xenon 135m				2,200		
Xenon 135				360		
Xenon 137				49,000		
Xenon 138				13,000		
Iodine 132				275		
Iodine 133				40.0		
Iodine 134				1,100		
Iodine 135				120		

a *Source terms are those of modular dry vault storage. The dry cask source terms for accident scenarios are the same or smaller than those of modular dry vault storage, therefore, the modular dry vault storage source term values are considered to be bounding values for the impact evaluations.*

b *Particulate source terms (from Strontium 89 to Curium 242) are 1000 times higher, if a facility does not have or has an ineffective, high efficiency particulate air filters. This condition is applicable to the Savannah River Site Wet Storage at RBOF and L-Reactor Disassembly Basin.*

The incident-free operation source terms for chemical separation at the Savannah River Site and the Idaho National Engineering Laboratory were taken from the Interim Management of Nuclear Materials Final EIS (DOE, 1995b) and the Programmatic SNF&INEL Final EIS (DOE, 1995g), respectively. Accident source terms for the chemical separation process were not developed for foreign research reactor spent nuclear fuel. It was considered that the consequences of chemical separation operations-related accidental scenarios are similar to those identified and analyzed in the above documents.

F.6.6.2 Site-Specific Parameters

Several site-specific parameters were required as input to the computer models. The site-specific parameters deal with meteorology, individual and general population food consumption rates, food production locations, and distances and directions of individuals and populations with respect to release locations. The food consumption rates apply only to the MEI and the population dose calculations as indicated in Table F-105. Site-specific food consumption rates consistent with those used in the Programmatic SNF&INEL Final EIS (DOE, 1995g) were utilized. Different contaminated food consumption rates were used at each site because the rate at each site is calculated based on the food production rate within an 80 km (50 mi) radius and the amount of supplemental food (uncontaminated food) that is imported from outside of the 80 km (50 mi) radius. If food production around the site is not sufficient for the population consumption rate, then uncontaminated food is imported. Otherwise, the consumed food is assumed to be contaminated.

F.6.6.3 Results

Tables F-109 through F-116 provide summaries of the consequences, in terms of mrem and/or person-rem, of postulated accident doses to the MEI, NPAI, worker and the public. Except for the worker, where the dose is calculated using the 50th-percentile meteorology, dose calculations were performed for both the 50th- and the 95th-percentile meteorologies using the assumptions and input values discussed above. The accident scenarios and source terms, as described earlier in this appendix, were generically applied to new dry and wet storage facilities. For the existing facilities at each management site, the assumptions and the related source terms were adjusted to conform to the conditions of each facility. Two types of results were provided for the offsite residents (MEI and population). Because protective action guidelines (EPA, 1991) specify mitigative actions to prevent consumption of contaminated food, the dose to offsite residents is reported for all pathways (i.e., external, inhalation, and ingestion) and without the ingestion pathway (i.e., external and inhalation). It should be noted that, as stated earlier, no reduction of exposure to the plume or to contaminated ground surface as a result of early evacuation of offsite populations due to protective action guidelines was accounted for in this analysis.

The analyses were performed for a generic wet and a generic dry storage facility at the Savannah River Site, the Idaho National Engineering Laboratory, the Hanford Site, the Oak Ridge Reservation, and the Nevada Test Site, as well as for site-specific locations (BNFP, L-Reactor Basin area, and RBOF at the Savannah River Site, and FMEF and WNP-4 Spray Pond at the Hanford Site). The consequences of accident scenarios for the IFSF (dry), CPP-749 (dry) and FAST (wet) storage areas at the Idaho National Engineering Laboratory are considered to be equal to those of a generic dry and a generic wet storage facility, respectively. The consequences of accident scenarios for E-MAD at Nevada Test Site are considered to be similar to that of a generic dry storage facility at Nevada Test Site. For the RBOF and the L-Reactor disassembly basin, the criticality accident source terms were adjusted to conform with the conditions assumed in the Basis for Interim Operation reports for these facilities (WSRC, 1995b and 1995c), where no credit was taken for high efficiency particulate air filters after a criticality accident.

Table F-109 Summary of the Accident Analysis Dose Assessments at the Savannah River Site Generic Storage Facilities - All Pathways

			95th-Percentile Meteorology			*50th-Percentile Meteorology*			
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*NPAI (mrem)*	*Population (person-rem)*	*MEI (mrem)*	*NPAI (mrem)*	*Worker (mrem)*	*Population (person-rem)*
Dry Storage Accidents - H-Area									
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF[b]	0.24 0.038 1.9×10^{-8}	0.068 0.011 5.5×10^{-9}	9.2 1.5 0.00075	0.055 0.0088 4.4×10^{-9}	0.0043 0.00069 3.5×10^{-10}	28 4.5 1.8×10^{-6}	0.62 0.099 0.000050
Dropped Fuel Cask	0.0001	Dose/event Dose/yr LCF[b]	0.018 1.8×10^{-6} 9.0×10^{-13}	0.00034 3.4×10^{-8} 1.7×10^{-14}	0.55 0.000055 2.8×10^{-8}	0.0039 3.9×10^{-7} 2.0×10^{-13}	0.000024 2.4×10^{-9} 1.2×10^{-15}	0.28 0.000028 1.1×10^{-11}	0.011 1.1×10^{-6} 5.5×10^{-10}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event Dose/yr LCF[b]	40 0.000040 2.0×10^{-11}	0.29 2.9×10^{-7} 1.5×10^{-13}	1300 0.0013 6.5×10^{-7}	8.9 8.9×10^{-6} 4.5×10^{-12}	0.019 1.9×10^{-8} 9.5×10^{-15}	120 0.00012 4.8×10^{-11}	87 0.000087 4.4×10^{-8}
New Wet Storage Accidents - H-Area									
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF[b]	0.0070 0.0011 5.5×10^{-10}	0.00039 0.000062 3.1×10^{-11}	0.23 0.037 0.000019	0.0016 0.00026 1.3×10^{-10}	0.000027 4.3×10^{-6} 2.2×10^{-12}	0.14 0.0022 8.8×10^{-10}	0.016 0.00026 1.3×10^{-7}
Accidental Criticality	0.0031	Dose/event Dose/yr LCF[b]	17 0.053 2.7×10^{-8}	9.5 0.030 1.5×10^{-8}	370 1.2 0.00060	4.0 0.012 6.0×10^{-9}	0.69 0.0021 1.1×10^{-9}	1600 5.0 2.0×10^{-6}	15 0.047 0.000024
Aircraft Crash	1×10^{-6}	Dose/event Dose/yr LCF[b]	4.1 4.1×10^{-6} 2.1×10^{-12}	0.98 9.8×10^{-7} 4.9×10^{-13}	150 0.00015 7.5×10^{-8}	0.92 9.2 x 10-7 4.6×10^{-13}	0.061 6.1×10^{-8} 3.1×10^{-14}	400 0.00040 1.6 x 10-10	10 0.000010 5.0×10^{-9}

Table F-109A Summary of the Accident Analysis Dose Assessments at the Savannah River Site Generic Storage Facilities - External and Inhalation Pathways

			95th-Percentile Meteorology		*50th-Percentile Meteorology*	
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*Population (person-rem)*	*MEI (mrem)*	*Population (person-rem)*
Dry Storage Accidents - H- Area						
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF[b]	0.053 0.0085 4.3×10^{-9}	3.1 0.050 0.000025	0.012 0.0019 9.5×10^{-10}	0.0011 0.00018 9.0×10^{-8}
Dropped Fuel Cask	0.0001	Dose/event Dose/yr LCF	0.00024 2.4×10^{-8} 1.2×10^{-14}	0.015 1.5×10^{-6} 7.5×10^{-10}	0.000055 5.5×10^{-9} 2.8×10^{-15}	0.00090 9.0×10^{-8} 4.5×10^{-11}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event Dose/yr LCF	0.91 9.1×10^{-7} 4.6×10^{-13}	55 0.000055 2.8×10^{-8}	0.20 2.0×10^{-7} 1.0×10^{-13}	0.037 3.7×10^{-8} 1.9×10^{-11}
New Wet Storage Accidents - H-Area						
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF	0.00027 0.000043 2.2×10^{-11}	0.017 0.0027 1.4×10^{-6}	0.000062 9.9×10^{-6} 5.0×10^{-12}	0.0010 0.00016 8.0×10^{-8}
Accidental Criticality	0.0031	Dose/event Dose/yr LCF	9.9 0.031 1.6×10^{-8}	240 0.74 0.00037	2.5 0.0078 3.9×10^{-9}	5.8 0.018 9.0×10^{-6}
Aircraft Crash	1×10^{-6}	Dose/event Dose/yr LCF	0.76 7.6×10^{-7} 3.8×10^{-13}	46 0.000046 2.3×10^{-8}	0.18 1.8×10^{-7} 9.0×10^{-14}	3.1 3.1×10^{-6} 1.6×10^{-9}

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Point Estimate of Latent Cancer Fatalities event/yr.*

Table F-110 Summary of the Accident Analysis Dose Assessments at the Idaho National Engineering Laboratory Generic Storage Facilities - All Pathways

			95th-Percentile Meteorology			50th-Percentile Meteorology			
	Frequency (event/yr)	Risk	MEI (mrem)[a]	NPAI (mrem)	Population (person-rem)	MEI (mrem)	NPAI (mrem)	Worker (mrem)	Population (person-rem)
Dry Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event	1.3	0.67	15	0.093	0.062	28	0.83
		Dose/yr	0.21	0.11	2.4	0.015	0.0099	4.5	0.13
		LCF[b]	1.1×10^{-7}	5.5×10^{-8}	0.0012	7.5×10^{-9}	5.0×10^{-9}	1.8×10^{-6}	0.000065
Dropped Fuel Cask	0.0001	Dose/event	0.074	0.0033	0.83	0.0052	0.00032	0.12	0.047
		Dose/yr	7.4×10^{-6}	3.3×10^{-7}	0.000083	5.2×10^{-7}	3.2×10^{-8}	0.000012	4.7×10^{-6}
		LCF	3.7×10^{-12}	1.7×10^{-13}	4.2×10^{-8}	2.6×10^{-13}	1.6×10^{-14}	4.8×10^{-12}	2.4×10^{-9}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event	180	2.9	2000	13	0.27	120	110
		Dose/yr	0.00018	2.9×10^{-6}	0.0020	0.000013	2.7×10^{-7}	0.00012	0.00011
		LCF	9.0×10^{-11}	1.5×10^{-12}	1.0×10^{-6}	6.5×10^{-12}	1.4×10^{-13}	4.8×10^{-11}	5.5×10^{-8}
Wet Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event	0.0016	0.0036	0.43	0.0028	0.00036	0.14	0.025
		Dose/yr	0.00026	0.00058	0.069	0.00045	0.000058	0.022	0.0040
		LCF	1.3×10^{-10}	2.9×10^{-10}	0.000035	2.3×10^{-10}	2.9×10^{-11}	8.8×10^{-9}	2.0×10^{-6}
Accidental Criticality	0.0031	Dose/event	28	30	140	3.4	12	1800	12
		Dose/yr	0.087	0.093	0.43	0.011	0.037	5.6	0.037
		LCF	4.4×10^{-8}	4.7×10^{-8}	0.00022	5.5×10^{-9}	1.9×10^{-8}	2.2×10^{-6}	0.000019
Aircraft Crash	1×10^{-6}	Dose/event	22	9.8	250	1.6	0.88	400	14
		Dose/yr	0.000022	9.8×10^{-6}	0.00025	1.6×10^{-6}	8.8×10^{-7}	0.00040	0.00014
		LCF	1.1×10^{-11}	4.9×10^{-12}	1.3×10^{-7}	8.0×10^{-13}	4.4×10^{-13}	1.6×10^{-10}	7.0×10^{-8}

Table F-110A Summary of the Accident Analysis Dose Assessments at the Idaho National Engineering Laboratory Generic Storage Facilities - External and Inhalation Pathways

			95th-Percentile Meteorology		50th-Percentile Meteorology	
	Frequency (event/yr)	Risk	MEI (mrem)[a]	Population (person-rem)	MEI (mrem)	Population (person-rem)
Dry Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event	0.23	2.7	0.017	0.15
		Dose/yr	0.037	0.43	0.0027	0.024
		LCF[b]	1.9×10^{-8}	0.00022	1.4×10^{-9}	0.000012
Dropped Fuel Cask	0.0001	Dose/event	0.0010	0.013	0.000079	0.00076
		Dose/yr	1.0×10^{-7}	1.3×10^{-6}	7.9×10^{-9}	7.6×10^{-8}
		LCF	5.0×10^{-14}	6.5×10^{-10}	4.0×10^{-15}	3.8×10^{-11}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event	4.0	0.45	0.29	2.6
		Dose/yr	4.0×10^{-6}	0.000045	2.9×10^{-7}	2.6×10^{-6}
		LCF	2.0×10^{-12}	2.3×10^{-8}	1.5×10^{-13}	1.3×10^{-9}
Wet Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event	0.0012	0.014	0.000090	0.00085
		Dose/yr	0.00019	0.0022	0.000014	0.00014
		LCF	9.5×10^{-11}	1.1×10^{-6}	7.0×10^{-12}	7.0×10^{-8}
Accidental Criticality	0.0031	Dose/event	17	26	2.6	5.4
		Dose/yr	0.053	0.081	0.0081	0.017
		LCF	2.7×10^{-8}	0.000041	4.1×10^{-9}	8.5×10^{-6}
Aircraft Crash	1×10^{-6}	Dose/event	3.4	39	0.25	2.1
		Dose/yr	3.4×10^{-6}	0.000039	2.5×10^{-7}	2.1×10^{-6}
		LCF	1.7×10^{-12}	2.0×10^{-8}	1.3×10^{-13}	1.1×10^{-9}

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Point Estimate of Latent Cancer Fatalities event/yr.*

Table F-111 Summary of the Accident Analysis Dose Assessments at the Hanford Site Generic Storage Facilities - All Pathways

			95th-Percentile Meteorology			*50th-Percentile Meteorology*			
	Frequency (event/yr)	***Risk***	***MEI (mrem)[a]***	***NPAI (mrem)***	***Population (person-rem)***	***MEI (mrem)***	***NPAI (mrem)***	***Worker (mrem)***	***Population (person-rem)***
Dry Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF[b]	3.0 0.48 2.4×10^{-7}	0.57 0.091 4.6×10^{-8}	42 6.7 0.0034	0.15 0.024 1.2×10^{-8}	0.061 0.0098 4.9×10^{-9}	50 8.0 3.2×10^{-6}	2.0 0.32 0.00016
Dropped Fuel Cask	0.0001	Dose/event Dose/yr LCF	0.26 0.000026 1.3×10^{-11}	0.0085 8.5×10^{-7} 4.3×10^{-13}	3.0 0.00030 1.5×10^{-7}	0.011 1.1×10^{-6} 5.5×10^{-13}	0.00031 3.1×10^{-8} 1.6×10^{-14}	0.22 0.000022 8.8×10^{-12}	0.15 0.000015 7.5×10^{-9}
Aircraft Crash w/Fire[c]	NA	---	NA	NA	NA	NA	NA	NA	NA
Wet Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF	0.13 0.021 1.1×10^{-8}	0.0033 0.00053 2.7×10^{-10}	1.6 0.26 0.00013	0.0064 0.0010 5.0×10^{-10}	0.00035 0.000056 2.8×10^{-11}	0.25 0.040 1.6×10^{-8}	0.078 0.013 6.5×10^{-6}
Accidental Criticality	0.0031	Dose/event Dose/yr LCF	64 0.20 1.0×10^{-7}	14 0.044 2.2×10^{-8}	740 2.3 0.0012	4.8 0.015 7.5×10^{-9}	12 0.037 1.9×10^{-8}	3600 11 4.4×10^{-6}	55 0.17 0.000085
Aircraft Crash[c]	NA	---	NA	NA	NA	NA	NA	NA	NA

Table F-111A Summary of the Accident Analysis Dose Assessments at the Hanford Site Generic Storage Facilities - External and Inhalation Pathways

			95th-Percentile Meteorology		*50th-Percentile Meteorology*	
	Frequency (event/yr)	***Risk***	***MEI (mrem)[a]***	***Population (person-rem)***	***MEI (mrem)***	***Population (person-rem)***
Dry Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF[b]	0.30 0.048 2.4×10^{-8}	6.5 1.0 0.00050	0.015 0.0024 1.2×10^{-9}	0.31 0.050 0.000025
Dropped Fuel Cask	0.0001	Dose/event Dose/yr LCF	0.0039 3.9×10^{-7} 2.0×10^{-13}	0.029 2.9×10^{-6} 1.5×10^{-9}	0.000071 7.1×10^{-9} 3.6×10^{-15}	0.0015 1.5×10^{-7} 7.5×10^{-11}
Aircraft Crash w/Fire[c]	NA	---	NA	NA	NA	NA
Wet Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF	0.0016 0.00026 1.3×10^{-10}	0.032 0.0051 2.6×10^{-6}	0.000079 0.000013 6.5×10^{-12}	0.0018 0.00029 1.5×10^{-7}
Accidental Criticality	0.0031	Dose/event Dose/yr LCF	7.9 0.025 1.3×10^{-8}	180 0.56 0.00028	2.0 0.0062 3.1×10^{-9}	27 0.084 0.000042
Aircraft Crash[c]	NA	---	NA	NA	NA	NA

NA = Not Applicable

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Point Estimate of Latent Cancer Fatalities event/yr.*

[c] *Aircraft crash accidents are not applicable to the Hanford Site since their frequency of occurrence is less than 10^{-7}/yr.*

Table F-112 Summary of the Accident Analysis Dose Assessments at the Oak Ridge Reservation Generic Storage Facilities - All Pathways

			95th-Percentile Meteorology			*50th-Percentile Meteorology*			
	Frequency (event/yr)	***Risk***	***MEI (mrem)[a]***	***NPAI (mrem)***	***Population (person-rem)***	***MEI (mrem)***	***NPAI (mrem)***	***Worker (mrem)***	***Population (person-rem)***
Dry Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event	22	42	55	2.1	9.4	140	8.4
		Dose/yr	3.5	6.7	8.8	0.34	1.5	22	1.3
		LCF[b]	1.8×10^{-6}	3.4×10^{-6}	0.0044	1.7×10^{-7}	7.5×10^{-7}	8.8×10^{-6}	0.00065
Dropped Fuel Cask	0.0001	Dose/event	1.4	0.18	15	0.14	0.042	0.61	2.3
		Dose/yr	0.00014	0.000018	0.0015	0.000014	4.2×10^{-6}	0.000061	0.00023
		LCF	7.0×10^{-11}	9.0×10^{-12}	7.5×10^{-7}	7.0×10^{-12}	2.1×10^{-12}	2.4×10^{-11}	1.2×10^{-7}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event	2300	180	2900	220	41	610	440
		Dose/yr	0.0023	0.00018	0.0029	0.00022	0.000041	0.00061	0.00044
		LCF	1.2×10^{-9}	9.0×10^{-11}	1.5×10^{-6}	1.1×10^{-10}	2.1×10^{-11}	2.4×10^{-10}	2.2×10^{-7}
Wet Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event	0.71	0.20	16	0.068	0.046	0.68	2.5
		Dose/yr	0.11	0.0032	2.6	0.011	0.0074	0.11	0.40
		LCF	5.5×10^{-8}	1.6×10^{-8}	0.0013	5.5×10^{-9}	3.7×10^{-9}	4.4×10^{-8}	0.00020
Accidental Criticality	0.0031	Dose/event	1500	3300	1400	230	910	6800	210
		Dose/yr	4.7	10	4.3	0.71	2.8	21	0.65
		LCF	2.4×10^{-6}	5.0×10^{-6}	0.0022	3.6×10^{-7}	1.4×10^{-6}	8.4×10^{-6}	0.00033
Aircraft Crash	1×10^{-6}	Dose/event	380	600	2900	29	130	1900	120
		Dose/yr	0.00038	0.00060	0.0029	0.000029	0.00013	0.0019	0.00012
		LCF	1.9×10^{-10}	3.0×10^{-10}	1.5×10^{-6}	1.5×10^{-10}	6.5×10^{-11}	7.6×10^{-10}	6.0×10^{-8}

Table F-112A Summary of the Accident Analysis Dose Assessments at the Oak Ridge Reservation Generic Storage Facilities - External and Inhalation Pathways

			95th-Percentile Meteorology		*50th-Percentile Meteorology*	
	Frequency (event/yr)	***Risk***	***MEI (mrem)[a]***	***Population (person-rem)***	***MEI (mrem)***	***Population (person-rem)***
Dry Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event	9.8	29	0.96	4.4
		Dose/yr	1.6	4.6	0.15	0.70
		LCF[b]	8.0×10^{-7}	0.0023	7.5×10^{-8}	0.00035
Dropped Fuel Cask	0.0001	Dose/event	0.038	0.13	0.0039	0.021
		Dose/yr	3.8×10^{-6}	0.000013	3.9×10^{-7}	2.1×10^{-6}
		LCF	1.9×10^{-12}	6.5×10^{-9}	2.0×10^{-13}	1.1×10^{-9}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event	180	500	17	76
		Dose/yr	0.00018	0.00050	0.000017	0.000076
		LCF	9.0×10^{-11}	2.5×10^{-7}	8.5×10^{-12}	3.8×10^{-8}
Wet Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event	0.042	0.14	0.0043	0.023
		Dose/yr	0.0067	0.022	0.00069	0.0037
		LCF	3.4×10^{-9}	0.000011	3.5×10^{-10}	1.9×10^{-6}
Accidental Criticality	0.0031	Dose/event	1100	1100	180	150
		Dose/yr	3.4	3.4	0.56	0.47
		LCF	1.7×10^{-6}	0.0017	2.8×10^{-7}	0.00024
Aircraft Crash	1×10^{-6}	Dose/event	140	420	13	61
		Dose/yr	0.00014	0.00042	0.000013	0.000061
		LCF	7.0×10^{-11}	2.1×10^{-7}	6.5×10^{-12}	3.1×10^{-8}

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Point Estimate of Latent Cancer Fatalities event/yr.*

Table F-113 Summary of the Accident Analysis Dose Assessments at the Nevada Test Site Generic Storage Facilities - All Pathways

			95th-Percentile Meteorology			50th-Percentile Meteorology			
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*NPAI (mrem)*	*Population (person-rem)*	*MEI (mrem)*	*NPAI (mrem)*	*Worker (mrem)*	*Population (person-rem)*
Dry Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event	1.7	0.31	1.5	0.052	0.0046	20	0.038
		Dose/yr	0.27	0.050	0.24	0.0083	0.00074	3.2	0.0060
		LCF[b]	1.4×10^{-7}	2.5×10^{-8}	0.00012	4.2×10^{-9}	3.7×10^{-10}	1.3×10^{-6}	3.0×10^{-9}
Dropped Fuel Cask	0.0001	Dose/event	0.11	0.0014	0.40	0.0033	0.000026	0.089	0.010
		Dose/yr	0.000011	1.4×10^{-7}	0.000040	3.3×10^{-7}	2.6×10^{-9}	8.9×10^{-6}	1.0×10^{-6}
		LCF	5.5×10^{-12}	7.0×10^{-14}	2.0×10^{-8}	1.7×10^{-13}	1.3×10^{-15}	3.6×10^{-12}	5.0×10^{-10}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event	180	1.2	250	5.6	0.020	87	6.2
		Dose/yr	0.00018	1.2×10^{-6}	0.00025	5.6×10^{-6}	2.0×10^{-8}	0.000087	6.2×10^{-6}
		LCF	9.0×10^{-11}	6.0×10^{-13}	1.3×10^{-7}	2.8×10^{-12}	1.0×10^{-14}	3.5×10^{-11}	3.1×10^{-9}
Wet Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event	0.054	0.0016	0.33	0.0017	0.000029	0.10	0.0084
		Dose/yr	0.0086	0.00026	0.053	0.00027	4.6×10^{-6}	0.016	0.0013
		LCF	4.2×10^{-9}	1.3×10^{-10}	0.000026	1.4×10^{-10}	2.3×10^{-12}	6.4×10^{-9}	6.5×10^{-7}
Accidental Criticality	0.0031	Dose/event	88	15	54	6.9	1.1	1300	1.9
		Dose/yr	0.27	0.047	0.17	0.021	0.0034	4.0	0.0059
		LCF	1.4×10^{-7}	2.3×10^{-8}	0.000084	1.1×10^{-8}	1.7×10^{-9}	0.000016	3.0×10^{-6}
Aircraft Crash	1×10^{-6}	Dose/event	29	4.2	61	0.92	0.067	290	1.6
		Dose/yr	0.000029	4.2×10^{-6}	0.000061	9.2×10^{-7}	6.7×10^{-8}	0.00029	1.6×10^{-6}
		LCF	1.5×10^{-11}	2.1×10^{-12}	3.1×10^{-8}	4.6×10^{-13}	3.4×10^{-14}	1.2×10^{-10}	8.0×10^{-10}

Table F-113A Summary of the Accident Analysis Dose Assessments at the Nevada Test Site Generic Storage Facilities - External and Inhalation Pathways

			95th-Percentile Meteorology		50th-Percentile Meteorology	
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*Population (person-rem)*	*MEI (mrem)*	*Population (person-rem)*
Dry Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event	0.78	0.26	0.024	0.0066
		Dose/yr	0.13	0.042	0.0038	0.0011
		LCF[b]	6.2×10^{-8}	0.000021	1.9×10^{-9}	5.3×10^{-7}
Dropped Fuel Cask	0.0001	Dose/event	0.0031	0.0011	0.00011	0.000033
		Dose/yr	3.1×10^{-7}	1.1×10^{-7}	1.1×10^{-8}	3.3×10^{-9}
		LCF	1.6×10^{-13}	5.5×10^{-11}	5.5×10^{-15}	1.7×10^{-12}
Aircraft Crash w/Fire	1×10^{-6}	Dose/event	13	4.5	0.41	0.12
		Dose/yr	0.000013	4.5×10^{-6}	4.1×10^{-7}	1.2×10^{-7}
		LCF	6.5×10^{-12}	2.3×10^{-9}	2.1×10^{-13}	6.0×10^{-11}
Wet Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event	0.0036	0.0013	0.00012	0.000037
		Dose/yr	0.00058	0.00021	0.000019	5.9×10^{-6}
		LCF	2.9×10^{-10}	1.1×10^{-7}	9.5×10^{-12}	3.0×10^{-9}
Accidental Criticality	0.0031	Dose/event	55	5.4	5.8	0.70
		Dose/yr	0.17	0.017	0.018	0.0022
		LCF	8.5×10^{-8}	8.5×10^{-6}	9.0×10^{-9}	1.1×10^{-6}
Aircraft Crash	1×10^{-6}	Dose/event	11	3.7	0.35	0.096
		Dose/yr	0.000011	3.7×10^{-6}	3.5×10^{-7}	9.6×10^{-8}
		LCF	5.5×10^{-12}	1.9×10^{-9}	1.8×10^{-13}	4.8×10^{-11}

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Point Estimate of Latent Cancer Fatalities event/yr.*

Table F-114 Summary of the Accident Analysis Dose Assessments at the Barnwell Nuclear Fuels Plant Wet Storage Facility[a] at the Savannah River Site - All Pathways

			95th-Percentile Meteorology			50th-Percentile Meteorology			
	Frequency (event/yr)	Risk	MEI (mrem)[b]	NPAI (mrem)	Population (Person-rem)	MEI (mrem)	NPAI (mrem)	Worker (mrem)	Population (Person-rem)
Wet Storage Accidents									
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF[c]	0.018 0.0056 2.8×10^{-9}	0.00099 0.00016 8.0×10^{-11}	0.028 0.0045 2.3×10^{-6}	0.0055 0.00088 4.4×10^{-10}	0.00027 0.000043 2.2×10^{-10}	0.00080 0.00013 5.2×10^{-11}	0.0033 0.00053 2.7×10^{-7}
Accidental Criticality	0.0031	Dose/event Dose/yr LCF	80 0.25 1.3×10^{-7}	75 0.23 1.2×10^{-7}	44 0.14 0.000070	42 0.13 6.5×10^{-8}	45 0.14 7.0×10^{-8}	75 0.23 9.2×10^{-8}	5.6 0.017 8.5×10^{-6}
Aircraft Crash	1×10^{-6}	Dose/event Dose/yr LCF	92 0.00092 4.6×10^{-10}	31 0.000031 1.6×10^{-11}	23 0.000023 1.2×10^{-8}	11 0.00011 5.5×10^{-11}	3.9 3.9×10^{-6} 2.0×10^{-12}	70 0.000070 2.8×10^{-10}	2.3 2.3×10^{-6} 1.2×10^{-9}

Table F-114A Summary of the Accident Analysis Dose Assessments at the Barnwell Nuclear Fuels Plant Wet Storage Facility[a] at the Savannah River Site - External and Inhalation Pathways

			95th-Percentile Meteorology		50th-Percentile Meteorology	
	Frequency (event/yr)	Risk	MEI (mrem)[b]	Population (person-rem)	MEI (mrem)	Population (person-rem)
Wet Storage Accidents						
Fuel Assembly Breach	0.16	Dose/event Dose/yr LCF[c]	0.00072 0.00012 6.0×10^{-11}	0.0021 0.00034 1.7×10^{-7}	0.00024 0.000038 1.9×10^{-12}	0.00021 0.000034 1.7×10^{-8}
Accidental Criticality	0.0031	Dose/event Dose/yr LCF	64 0.20 1.0×10^{-7}	27 0.084 0.000042	37 0.12 6.0×10^{-8}	3.7 0.012 6.0×10^{-6}
Aircraft Crash	1×10^{-6}	Dose/event Dose/yr LCF	17 0.000017 8.5×10^{-12}	6.9 6.9×10^{-6} 3.5×10^{-9}	2.0 2.0×10^{-6} 1.0×10^{-12}	0.68 6.8×10^{-7} 3.4×10^{-10}

[a] *Emissions will be released through an elevated stack for Accidental Criticality and Fuel Assembly Breach accidents.*

[b] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[c] *Point Estimate of Latent Cancer Fatalities event/yr.*

Table F-115 Summary of the Accident Analysis Dose Assessments at the Receiving Basin for Offsite Fuels and L-Reactor Basin Wet Storage Facilities at the Savannah River Site-All Pathways

			95th-Percentile Meteorology			*50th-Percentile Meteorology*			
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*NPAI (mrem)*	*Population (person-rem)*	*MEI (mrem)*	*NPAI (mrem)*	*Worker (mrem)*	*Population (person-rem)*
Wet Storage Accidents - RBOF									
Fuel Assembly Breach	0.16	Dose/event	0.0070	0.00039	0.23	0.0016	0.000027	0.14	0.016
		Dose/yr	0.0011	0.000062	0.037	0.00026	4.3×10^{-6}	0.0022	0.00026
		LCF[b]	5.5×10^{-10}	3.1×10^{-11}	0.000019	1.3×10^{-10}	2.2×10^{-12}	8.8×10^{-10}	1.3×10^{-7}
Accidental Criticality	0.0031	Dose/event	130	44	4800	30	2.9	16000	310
		Dose/yr	0.40	0.14	14.9	0.093	0.0090	50	0.96
		LCF	2.0×10^{-7}	7.0×10^{-8}	0.0074	4.7×10^{-8}	4.5×10^{-9}	0.000020	0.00048
Aircraft Crash	1×10^{-6}	Dose/event	4.1	0.98	150	0.92	0.061	400	10
		Dose/yr	4.1×10^{-6}	9.8×10^{-7}	0.00015	9.2×10^{-7}	6.1×10^{-8}	0.00040	0.000010
		LCF	2.1×10^{-12}	4.9×10^{-13}	7.5×10^{-8}	4.6×10^{-13}	3.1×10^{-14}	1.6×10^{-10}	5.0×10^{-9}
Wet Storage Accidents- L-Reactor Basin[c]									
Fuel Assembly Breach/	0.16	Dose/event	0.0093	0.00097	0.14	0.0011	0.00015	0.11	0.022
		Dose/yr	0.0015	0.00016	0.022	0.00018	0.00024	0.018	0.0035
		LCF	7.4×10^{-10}	8.0×10^{-11}	0.000011	8.8×10^{-11}	1.2×10^{-11}	7.1×10^{-9}	1.8×10^{-6}
Accidental Criticality	0.0031	Dose/event	170	120	3000	21	21	14000	440
		Dose/yr	0.527	0.37	9.3	0.065	0.065	43	1.4
		LCF	2.6×10^{-7}	1.9×10^{-7}	0.0047	3.3×10^{-8}	3.3×10^{-8}	0.000017	0.00070
Aircraft Crash	1×10^{-6}	Dose/event	4.2	2.6	93	0.60	0.39	70	14
		Dose/yr	4.2×10^{-6}	2.6×10^{-6}	0.000093	6.0×10^{-7}	3.9×10^{-7}	0.000070	0.000014
		LCF	2.1×10^{-12}	1.3×10^{-12}	4.7×10^{-8}	3.0×10^{-13}	2.0×10^{-13}	2.8×10^{-11}	7.0×10^{-9}

Table F-115A Summary of the Accident Analysis Dose Assessments at the Receiving Basin for Offsite Fuels and L-Reactor Basin Wet Storage Facilities at the Savannah River Site-External and Inhalation Pathways

			95th-Percentile Meteorology		*50th-Percentile Meteorology*	
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*Population (person-rem)*	*MEI (mrem)*	*Population (person-rem)*
Wet Storage Accidents - RBOF						
Fuel Assembly Breach	0.16	Dose/event	0.00027	0.017	0.000062	0.0010
		Dose/yr	0.000043	0.0027	9.9×10^{-6}	0.00016
		LCF[b]	2.2×10^{-11}	1.4×10^{-6}	5.0×10^{-12}	8.0×10^{-8}
Accidental Criticality	0.0031	Dose/event	38	1900	8.8	120
		Dose/yr	0.12	5.9	0.027	0.37
		LCF	5.9×10^{-8}	0.0029	1.4×10^{-8}	0.00019
Aircraft Crash	1×10^{-6}	Dose/event	0.76	46	0.18	3.1
		Dose/yr	7.6×10^{-7}	0.000046	1.8×10^{-7}	3.1×10^{-6}
		LCF	3.8×10^{-13}	2.3×10^{-8}	9.0×10^{-14}	1.6×10^{-9}
Wet Storage Accidents - L-Reactor Basin[c]						
Fuel Assembly Breach	0.16	Dose/event	0.00034	0.010	0.000041	0.0016
		Dose/yr	0.000054	0.0016	6.6×10^{-6}	0.00026
		LCF	2.7×10^{-11}	8.0×10^{-7}	3.3×10^{-12}	1.3×10^{-7}
Accidental Criticality	0.0031	Dose/event	50	1200	6.5	170
		Dose/yr	0.16	3.72	0.020	0.53
		LCF	7.8×10^{-8}	0.0019	1.1×10^{-8}	0.00026
Aircraft Crash	1×10^{-6}	Dose/event	0.77	28	0.11	4.2
		Dose/yr	7.7×10^{-7}	0.000028	1.1×10^{-7}	4.2×10^{-6}
		LCF	3.9×10^{-13}	1.4×10^{-8}	5.5×10^{-14}	2.1×10^{-9}

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Point Estimate of Latent Cancer Fatalities event per year.*

Table F-116 Summary of the Accident Analysis Dose Assessments for the Fuel Material Examination Facility Dry Storage and WNP-4 Wet Storage Facilities at the Hanford Site - All Pathways

			95th-Percentile Meteorology			50th-Percentile Meteorology			
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*NPAI (mrem)*	*Population (person-rem)*	*MEI (mrem)*	*NPAI (mrem)*	*Worker (mrem)*	*Population (person-rem)*
Dry Storage Accidents at FMEF[b]									
Fuel Assembly Breach	0.16	Dose/event	4.7	2.1	46	0.42	0.25	0.99	5.7
		Dose/yr	0.75	0.34	7.4	0.067	0.040	0.16	0.91
		LCF[c]	3.7×10^{-7}	1.7×10^{-7}	0.0037	3.4×10^{-8}	2.0×10^{-8}	6.4×10^{-8}	0.00046
Dropped Fuel Cask	0.0001	Dose/event	0.2	0.032	3.2	0.017	0.0017	0.0049	0.41
		Dose/yr	0.00002	3.2×10^{-6}	0.00032	1.7×10^{-6}	1.7×10^{-7}	4.9×10^{-7}	0.000041
		LCF	8×10^{-12}	1.6×10^{-12}	3.2×10^{-7}	8.5×10^{-13}	8.5×10^{-14}	2.5×10^{-13}	2.1×10^{-8}
Aircraft Crash w/Fire[d]	NA	---	NA	NA	NA	NA	NA	NA	NA
Wet Storage Accidents at WNP-4[b]									
Fuel Assembly Breach	0.16	Dose/event	0.15	0.0033	1.3	0.018	0.00060	0.00024	0.13
		Dose/yr	0.024	0.00053	0.21	0.0029	0.000096	0.000038	0.021
		LCF	1.2×10^{-8}	2.7 x 10-10	0.00011	1.5×10^{-9}	4.8×10^{-11}	1.5×10^{-11}	0.000011
Accidental Criticality	0.0031	Dose/event	97	76	620	20	45	120	160
		Dose/yr	0.3	0.24	1.9	0.062	0.14	0.37	0.50
		LCF	1.5×10^{-7}	1.2×10^{-7}	0.00096	3.1×10^{-8}	7.0×10^{-8}	1.5×10^{-7}	0.00025
Aircraft Crash[d]	NA	---	NA	NA	NA	NA	NA	NA	NA

Table F-116A Summary of the Accident Analysis Dose Assessments for the Fuel Material Examination Facility Dry Storage and WNP-4 Wet Storage Facilities at the Hanford Site - External and Inhalation Pathways

			95th-Percentile Meteorology		50th-Percentile Meteorology	
	Frequency (event/yr)	*Risk*	*MEI (mrem)*[a]	*Population (person-rem)*	*MEI (mrem)*	*Population (person-rem)*
Dry Storage Accidents at FMEF[b]						
Fuel Assembly Breach	0.016	Dose/event	0.46	6.6	0.041	0.79
		Dose/yr	0.074	1.1	0.0066	0.12
		LCFc	3.7×10^{-8}	0.00055	3.3×10^{-9}	0.000060
Dropped Fuel Cask	0.0001	Dose/event	0.0028	0.04	0.00025	0.0057
		Dose/yr	2.8×10^{-7}	4.0×10^{-6}	2.5×10^{-8}	5.7×10^{-7}
		LCF	1.4×10^{-13}	2.0×10^{-9}	1.2×10^{-14}	2.9×10^{-10}
Aircraft Crash w/Fire[d]	NA	---	NA	NA	NA	NA
Wet Storage Accidents at WNP-4[b]						
Fuel Assembly Breach	0.16	Dose/event	0.0023	0.032	0.00028	0.0034
		Dose/yr	0.00037	0.0051	0.000045	0.00054
		LCF	1.8×10^{-9}	2.6×10^{-6}	2.2×10^{-11}	2.7×10^{-7}
Accidental Criticality	0.0031	Dose/event	32	180	12	120
		Dose/yr	0.099	0.56	0.037	0.37
		LCF	5.0×10^{-9}	0.00028	1.9×10^{-8}	0.00019
Aircraft Crash[d]	NA	---	NA	NA	NA	NA

NA = Not Applicable

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Emissions will be released through an elevated stack for Fuel Assembly Breach, Dropped Fuel Cask, and Accidental Criticality Accidents.*

[c] *Point Estimate of Latent Cancer Fatalities event/yr.*

[d] *Aircraft Crash accidents are not applicable to the Hanford Site since their frequency of occurrence is less than 10^{-7} event/yr.*

Table F-117 provides a summary of the consequences of radiation exposure to the public and to the MEI from emissions in wet storage (generic and existing), and dry storage (generic and existing).

Table F-117 Normal Release Dose Assessments and Latent Cancer Fatalities at Storage Sites

	MEI Dose (mrem/yr)	*MEI Risk (LCF/yr)*	*Population Dose (person-rem/yr)*	*Population Risk (LCF/yr)*
Savannah River Site				
Receipt/Unloading at:				
RBOF	1.1×10^{-4}	5.5×10^{-11}	5.7×10^{-3}	2.8×10^{-6}
L-Reactor Basin	7.3×10^{-5}	3.7×10^{-11}	4.6×10^{-3}	2.3×10^{-6}
BNFP	6.5×10^{-4}	3.3×10^{-10}	4.5×10^{-3}	2.3×10^{-6}
New Dry Storage Facility	1.8×10^{-4}	9.0×10^{-11}	8.6×10^{-3}	4.3×10^{-6}
New Wet Storage Facility	1.1×10^{-4}	5.5×10^{-11}	5.7×10^{-3}	2.8×10^{-6}
Storage at:				
RBOF	1.2×10^{-9}	6.0×10^{-16}	6.2×10^{-8}	3.1×10^{-11}
L-Reactor Basin[a]	3.6×10^{-4}	1.8×10^{-10}	2.2×10^{-2}	1.1×10^{-5}
BNFP	7.5×10^{-9}	3.8×10^{-15}	4.8×10^{-8}	2.4×10^{-11}
New Dry Storage Facility	0	0	0	0
New Wet Storage Facility	1.2×10^{-9}	6.0×10^{-16}	6.2×10^{-8}	3.1×10^{-11}
Idaho National Engineering Laboratory				
Receipt/Unloading at:				
IFSF (dry storage)	5.6×10^{-4}	2.8×10^{-10}	4.5×10^{-3}	2.3×10^{-6}
FAST (wet storage)	3.8×10^{-4}	1.9×10^{-10}	3.1×10^{-3}	1.6×10^{-6}
CPP-749 (dry storage)	5.6×10^{-4}	2.8×10^{-10}	4.5×10^{-3}	2.3×10^{-6}
New Dry Storage Facility	5.6×10^{-4}	2.8×10^{-10}	4.5×10^{-3}	2.3×10^{-6}
New Wet Storage Facility	3.8×10^{-4}	1.9×10^{-10}	3.1×10^{-3}	1.6×10^{-6}
Storage at:				
IFSF (dry storage)	0	0	0	0
FAST (wet storage)	3.8×10^{-9}	1.9×10^{-15}	3.1×10^{-8}	1.6×10^{-11}
CPP-749 (dry storage)	0	0	0	0
New Dry Storage Facility	0	0	0	0
New Wet Storage Facility	3.8×10^{-9}	1.9×10^{-15}	3.1×10^{-8}	1.6×10^{-11}
Hanford Site				
Receipt/Unloading at:				
FMEF (dry storage)	2.0×10^{-4}	1.0×10^{-10}	1.1×10^{-2}	5.5×10^{-6}
WNP-4 Spray Pond (wet storage)	2.2×10^{-4}	1.1×10^{-10}	5.8×10^{-3}	2.9×10^{-6}
New Dry Storage Facility	2.5×10^{-4}	1.3×10^{-10}	1.5×10^{-2}	7.5×10^{-6}
New Wet Storage Facility	2.0×10^{-4}	1.0×10^{-10}	1.2×10^{-2}	6.0×10^{-6}
Storage at:				
FMEF (dry storage)	0	0	0	0
WNP-4 Spray Pond (wet storage)	5.9×10^{-10}	3.0×10^{-16}	1.6×10^{-8}	8.0×10^{-12}
New Dry Storage Facility	0	0	0	0
New Wet Storage Facility	8.8×10^{-10}	4.4×10^{-16}	6.9×10^{-8}	3.5×10^{-11}
Oak Ridge Reservation				
Receipt/Unloading at:				
New Dry Storage Facility	8.9×10^{-2}	4.5×10^{-8}	8.5×10^{-2}	4.3×10^{-5}
New Wet Storage Facility	6.0×10^{-2}	3.0×10^{-8}	6.1×10^{-2}	3.1×10^{-5}
Storage at:				
New Dry Storage Facility	0	0	0	0
New Wet Storage Facility	4.6×10^{-7}	2.3×10^{-13}	5.0×10^{-7}	2.5×10^{-10}

	MEI Dose (mrem/yr)	MEI Risk (LCF/yr)	Population Dose (person-rem/yr)	Population Risk (LCF/yr)
Nevada Test Site				
Receipt/Unloading at:				
E-MAD (dry storage)	7.6×10^{-4}	3.8×10^{-10}	9.3×10^{-4}	4.7×10^{-7}
New Dry Storage Facility	7.6×10^{-4}	3.8×10^{-10}	9.3×10^{-4}	4.7×10^{-7}
New Wet Storage Facility	5.2×10^{-4}	2.6×10^{-10}	5.2×10^{-4}	2.6×10^{-7}
Storage at:				
E-MAD (dry storage)	0	0	0	0
New Dry Storage Facility	0	0	0	0
New Wet Storage Facility	4.0×10^{-9}	2.0×10^{-15}	4.7×10^{-9}	2.0×10^{-12}

[a] *L-Reactor basin doses are due to existing conditions; the foreign research reactor spent nuclear fuel contribution would be six orders of magnitude smaller*

F.6.7 Accident Scenarios Involving Target Materials

A review of the hypothetical accident scenarios analyzed for spent nuclear fuel indicates that only the aircraft crash with fire accident is applicable to the target materials. The frequency of occurrence of an accident involving target materials is estimated to be 3 percent of the 1×10^{-6} per year frequency figure used in the spent nuclear fuel accident analysis. This is because the number of transfer casks that would involve target material is less than 3 percent of that used for 22,700 spent nuclear fuel elements. Therefore, the frequency of this scenario is less than 10^{-7} per year, and is considered to be unforeseeable. Nonetheless, this accident was analyzed and its consequences at potential storage locations were summarized in Table F-118. The frequency of this accident is set conservatively at 10^{-7} per year.

The process by which target materials are prepared for shipment [i.e., drying and canning of the target material solutions, (see Appendix B, Section B.1.5)] releases all gaseous fission products (noble gases and halogens). In addition, the cans in which target materials would be packed do not require any further cutting when they are received in a storage facility. A review of the hypothetical accident scenarios analyzed for spent nuclear fuel indicates that only the aircraft crash with fire accident would be applicable to the target materials. The cans are never cut, and there are no gaseous fission products; therefore, fuel element breach and fuel cask drop scenarios would not be applicable. In addition, should there be an aircraft crash into the wet storage pool where the target material is stored; or, if an accidental criticality in the pool were to occur, the radioactivity releases would be bound by that of the spent nuclear fuel analyzed for these accidents. This is because the amount of radioactive inventory per target material can is very small compared to that in the bounding spent nuclear fuel. In addition, any releases from the target cans would be absorbed in the pool.

Therefore, a scenario involving an aircraft crash into a dry storage facility with ensuing fire was analyzed for the target materials. The scenario assumptions are similar to those described in Section F.6.4.4.3. Because of the size of each can, it was assumed that the transfer cask involved in the accident would contain 40 cans of target materials containing maximum radionuclide inventories, (i.e., 40 cans of 200 grams of ^{235}U per can cooled for at least 3 years). The overall respirable release fraction is assumed to be 5×10^{-3} (Neuhauser and Kanipe, 1993). Table F-119 shows the radioactivity release source terms for this accident.

Table F-118 Summary of the Accident Analysis Dose Assessments for the Aircraft Crash Accident with Fire Involving Target Material - All Pathways

			95 Percent Meteorology			50 Percent Meteorology			
Site[c]	Frequency (event/yr)	Risk	MEI (mrem)[a]	NPAI (mrem)	Population (person-rem)	MEI (mrem)	NPAI (mrem)	Worker (mrem)	Population (person-rem)
NTS		Dose/event	180	28	120	5.6	0.45	2000	3.0
		Dose/yr	0.000018	2.8×10^{-6}	0.000012	5.6×10^{-7}	4.5×10^{-8}	0.00020	3.0×10^{-7}
	1×10^{-7}	LCF[b]	9.0×10^{-12}	1.4×10^{-12}	6.0×10^{-9}	2.8×10^{-13}	2.3×10^{-14}	8.0×10^{-11}	1.5×10^{-10}
ORR		Dose/event	2400	4000	3700	230	910	14000	560
		Dose/yr	0.00024	0.00040	0.00037	0.000023	0.000091	0.0014	0.000056
	1×10^{-7}	LCF	1.2×10^{-10}	2.0×10^{-10}	1.9×10^{-7}	1.2×10^{-11}	4.6×10^{-11}	5.6×10^{-10}	2.8×10^{-8}
INEL		Dose/event	130	63	1500	9.3	5.7	2700	84
		Dose/yr	0.000013	6.3×10^{-6}	0.00015	9.3×10^{-7}	5.7×10^{-7}	0.00027	8.4×10^{-6}
	1×10^{-7}	LCF	6.5×10^{-12}	6.3×10^{-12}	7.5×10^{-8}	4.7×10^{-13}	2.9×10^{-13}	1.1×10^{-10}	4.2×10^{-9}
SRS		Dose/event	26	6.3	970	5.8	0.41	2700	66
		Dose/yr	2.6×10^{-6}	6.3×10^{-7}	0.000097	5.8×10^{-7}	4.1×10^{-8}	0.00027	6.6×10^{-6}
	1×10^{-7}	LCF	1.3×10^{-12}	3.2×10^{-13}	4.9×10^{-8}	2.9×10^{-13}	2.1×10^{-14}	1.1×10^{-10}	3.3×10^{-9}

Table F-118A Summary of the Accident Analysis Dose Assessments for the Aircraft Crash Accident with Fire Involving Target Material - External and Inhalation Pathways

			95 Percent Meteorology		50 Percent Meteorology	
Site[c]	Frequency (event/yr)	Risk	MEI (mrem)[a]	Population (person-rem)	MEI (mrem)	Population (person-rem)
NTS		Dose/event	64	22	2.1	0.57
		Dose/yr	6.4×10^{-6}	2.2×10^{-6}	2.1×10^{-7}	5.7×10^{-8}
	1×10^{-7}	LCF[b]	3.2×10^{-12}	1.1×10^{-9}	1.1×10^{-13}	2.9×10^{-11}
ORR		Dose/event	870	2500	83	560
		Dose/yr	0.000087	0.00025	8.3×10^{-6}	0.000056
	1×10^{-7}	LCF	4.4×10^{-11}	1.3×10^{-7}	4.2×10^{-12}	2.8×10^{-8}
INEL		Dose/event	20	230	1.4	12
		Dose/yr	2.0×10^{-6}	0.000023	1.4×10^{-7}	1.2×10^{-6}
	1×10^{-7}	LCF	1.0×10^{-12}	1.2×10^{-8}	7.0×10^{-14}	6.0×10^{-10}
SRS		Dose/event	4.4	270	1.0	19
		Dose/yr	4.4×10^{-7}	0.000027	1.0×10^{-7}	1.9×10^{-6}
	1×10^{-7}	LCF	2.2×10^{-13}	1.4×10^{-8}	5.0×10^{-12}	9.5×10^{-10}

NTS = Nevada Test Site; ORR = Oak Ridge Reservation; INEL = Idaho National Engineering Laboratory; SRS = Savannah River Site

[a] *To convert to sieverts from mrem, divide by 100,000; to convert to person-sieverts from person-rem, divide by 100.*

[b] *Point Estimate of Latent Cancer Fatalities event/ yr.*

[c] *Aircraft crash accidents are not applicable to the Hanford Site since their frequency of occurrence is much less than 10^{-7} event/yr.*

Table F-119 Target Materials Aircraft Crash with Fire Accident Source Terms

Isotope	*Curies*
Strontium-89	2.4×10^{-4}
Strontium-90	3.1×10^{0}
Yttrium-90	3.1×10^{0}
Yttrium-91	1.4×10^{-3}
Zirconium-95	5.2×10^{-3}
Niobium-95	1.1×10^{-2}
Rubidium-103	2.1×10^{-6}
Rubidium-106	7.9×10^{-1}
Ruthenium-103m	2.1×10^{-6}
Tin-123	1.1×10^{-3}
Antimony-125	8.2×10^{-2}
Tellurium-125m	2.0×10^{-2}
Tellurium-127m	2.2×10^{-3}
Tellurium-129m	6.0×10^{-9}
Cesium-134	6.5×10^{-3}
Cesium-137	3.0×10^{-1}
Cerium-141	7.4×10^{-8}
Cerium-144	7.7×10^{0}
Presidium-144	7.7×10^{0}
Promethium-147	6.3×10^{0}
Promethium-148m	2.5×10^{-9}
Europium-154	1.4×10^{-3}
Europium-155	5.2×10^{-2}
Uranium-234	1.4×10^{-7}
Uranium-235	8.3×10^{-5}
Uranium-238	1.5×10^{-6}
Plutonium-238	3.3×10^{-6}
Plutonium-239	6.2×10^{-4}
Plutonium-240	1.4×10^{-5}
Plutonium-241	1.3×10^{-4}
Americium-241	6.9×10^{-7}
Americium-242m	4.4×10^{-12}
Americium-243	3.1×10^{-12}
Curium-242	6.8×10^{-12}
Curium-244	3.2×10^{-12}

F.7 Costs

The cost of implementing the proposed action is analyzed in this section. For the purpose of the cost analysis, the alternatives described in Section 2.1 of the EIS were adjusted to reflect the Record of Decision on the Programmatic SNF&INEL Final EIS (DOE, 1995g) issued in May 1995. According to this Record of Decision, if foreign research reactor spent nuclear fuel is managed in the United States, the aluminum-based portion would be managed at the Savannah River Site and the TRIGA portion would be managed at the Idaho National Engineering Laboratory. The cost analysis also considers the financing arrangements discussed in Sections 2.2.1.2 and 2.2.2.3 of the EIS that would affect the cost to the United States. The cost information is presented as follows:

F.7.1 Summary of Cost Information

F.7.2 Costs of Individual Program Components

F.7.3 Interpreting the Minimum Program Costs

F.7.4 Interpreting the Other Cost Factors

F.7.1 Summary of Cost Information

This section presents total costs for the proposed policy and implementation alternatives that would impact the costs. The costs are presented in two parts: 1) minimum discounted costs (base case) for the well-defined program components and integration approaches, and 2) "other cost factors" that are likely but sufficiently uncertain that they cannot be directly included in the minimum discounted costs. The costs are shown as net present values in a consistent accounting framework.

Several important factors are used when estimating costs. These factors are as follows:

- *Site- and Implementation-Specific Facilities* - All costs for management in the United States are for facilities that exist or are planned at either the Savannah River Site or the Idaho National Engineering Laboratory. Costs are allocated to the program in proportion to the share of foreign research reactor spent nuclear fuel managed or transferred at each facility. This allocation of capital and operating costs within larger programs results in lower costs to the program than would be the case for the use of facilities dedicated to foreign research reactor spent nuclear fuel.

- *Schedule of Activities* - For all management alternatives (except total management overseas), all spent nuclear fuel is shipped, managed for 40 years, and disposed (either as spent nuclear fuel or as reprocessing waste) on schedules that are appropriate for the selected facilities.

- *Discount Rate* - The base case costs are discounted to 1996 at the rate specified by the Office of Management and Budget for the year ending February 1996. This rate is 4.9 percent real. The base case costs for management outside the United States are discounted at a 3 percent real rate of interest. This rate is estimated to be the long-term real rate of interest that can be expected on a trust fund outside the United States. If the net present value of the costs of the program are received in 1996, a hypothetical trust fund invests the money at the real discount rate so that future expenditures are made out of principal and accrued interest.

- *Net Present Value* - Net present value is a figure-of-merit for decision-making on the basis of life-cycle cost, not a value used for establishing budgets or cash flows. All costs are shown in constant 1996 dollars discounted to 1996. This means that the costs for the duration of the program, expressed as a net present value, are due and payable on January 1, 1996, not in the year the costs are incurred.

- *Timing of Expenses* - All costs are assumed to be incurred on the last day of each year of the 40-year management period. The principal and accrued interest in the trust funds (at the net present value of the program costs) are exactly sufficient to meet the costs as they are incurred.

- *Timing of Payments* - Deferring payments beyond January 1, 1996 increases the payments required (either from reactor operators or the United States Congress) by a factor based on the discount rate and the deferral. Pro-forma full-cost recovery fees are shown for payments made on December 31 of each of the 13 receipt years (1996 through 2008).

- *Inflation and Escalation* - Costs are expressed in constant 1996 dollars in this analysis, so the effects of inflation are eliminated. No costs are escalated in real terms.

- *Ultimate Disposition* - Estimated costs for geologic disposal of intact spent nuclear fuel or waste from chemical separation are included to provide a complete life-cycle cost analysis.

F.7.1.1 Scenarios Analyzed

For the purpose of the cost analysis, six scenarios were analyzed. The scenarios reflect the alternatives that affect cost directly, are consistent with the Record of Decision of the Programmatic SNF&INEL Final EIS (DOE, 1995g) and include the costs for ultimate disposal. The six cost scenarios are:

1. *Management Alternative 1 (Storage)* - Storage of aluminum-based foreign research reactor spent nuclear fuel at the Savannah River Site with new dry or wet storage facilities; storage of TRIGA foreign research reactor spent nuclear fuel at the Idaho National Engineering Laboratory at existing wet or dry storage facilities.

2. *Management Alternative 1 (revised to incorporate chemical separation)* - Chemical separation of aluminum-based foreign research reactor spent nuclear fuel at the Savannah River Site; storage of TRIGA foreign research reactor spent nuclear fuel at the Idaho National Engineering Laboratory.

3. *Management Alternative 1 (revised to incorporate a new technology)* — Implementation of a new treatment and/or packaging technology for aluminum-based foreign research reactor spent nuclear fuel and target material at the Savannah River Site; storage of TRIGA foreign research reactor spent nuclear fuel at the Idaho National Engineering Laboratory.

4. *Target Material* - Storage of target material at the Savannah River Site. This scenario provides the cost differential that can be used to assess the cost of managing target material in addition to the foreign research reactor spent nuclear fuel in Management Alternative 1 storage and chemical separation scenarios.

5. *Management Alternative 2* - Management of all foreign research reactor spent nuclear fuel overseas. This scenario reflects a combination of reprocessing and dry storage overseas. Countries with the capability to accept the waste from reprocessing are assumed to have their spent nuclear fuel reprocessed. The rest use dry storage.

6. *Management Alternative 3* - Chemical separation of a portion of the aluminum-based foreign research reactor spent nuclear fuel at the Savannah River Site; reprocessing of the remainder of aluminum-based foreign research reactor spent nuclear fuel overseas; storage of TRIGA foreign research reactor spent nuclear fuel at the Idaho National Engineering Laboratory.

By varying the quantities of material managed in different ways in the United States and overseas, different cost scenarios can be generated. The costs of these variations are bounded by the costs of the scenarios described above. For instance, a management alternative that includes acceptance of target material into the United States would be represented by a combination of Scenarios 1 and 4 or 2 and 4.

The implementation alternatives under Management Alternative 1 related to alternative amounts of foreign research reactor spent nuclear fuel eligible under the policy (Section 2.2.2.1), and alternative policy durations (Section 2.2.2.2), were not considered separately in the cost analysis because they are bounded by the cost scenarios analyzed. These implementation alternatives reduce the amount of foreign research reactor spent nuclear fuel eligible under the policy.

The implementation alternative under Management Alternative 1 related to alternative locations for taking title to the foreign research reactor spent nuclear fuel (Section 2.2.2.4) was not considered because it does not affect the cost analysis.

F.7.1.2 Minimum Program Costs

Table F-120 shows the minimum discounted program costs (base case) for the six scenarios defined above. These costs cover all foreign research reactor spent nuclear fuel shipments, management over 40 years, and geologic disposal. Uncertainties (risks) and escalation are zero. The schedule for activities in Europe under Management Alternative 3 is similar to that in the United States but not exactly the same. Reprocessing takes place over 13 years at Dounreay (the same timespan used for chemical separation at the Savannah River Site) although it could be completed at Dounreay in 9 or 10 years. Dounreay's charges for reprocessing are based on 1996 costs, not costs for 1996 through 2008 averaged over the 13-year period (as was done for the Savannah River Site). Geologic disposal takes place in 2025 through 2030 in Europe and 2030 through 2035 in the United States. Costs are discounted at 3 percent for the portion to be managed overseas and at 4.9 percent for the portion to be managed in the United States.

Table F-120 Minimum Program Costs (Net Present Value, Millions of 1996 Dollars in 1996)

Scenario	*Net Present Value*
1. Management Alternative 1 (Storage)	725/775[a]
2. Management Alternative 1 (revised to incorporate Chemical Separation)	625
3. Management Alternative 1 (revised to incorporate a New Technology)[b]	625-950
4. Target Material	35
5. Management Alternative 2	1,250
6. Management Alternative 3	675

[a] *Dry/Wet new storage facilities*

[b] *Includes target material*

Because of the uncertainties involved with the implementation of the new technology, the cost for Scenario 3 is presented as a range as discussed in Appendix F, Section F.7.2.9. Also, shipping costs in Scenario 3 include the assumption that of the total number of cask shipments, only 38 cask shipments would be accepted at the West Coast.

F.7.1.3 Other Cost Factors

There are four important sources of cost risk (excluding escalation) that are not part of the minimum costs in Table F-120. Table F-121 shows the likely values (risks) for these factors, taking into account the absolute values of the uncertainties and their probability of occurrence. A brief summary of these cost factors follows the table.

The other cost factors summarized in Table F-121 are as follows:

1. *Systems Integration and Logistics Risks* - Significant risks exist in the details of the policy implementation. The implementation of the policy would involve up to 41 foreign countries, up to 13 years of receipts, dozens of foreign ports, up to ten domestic ports, two U.S.

Table F-121 Other Cost Factors
(Net Present Value, Millions of 1996 Dollars in 1996)

Scenario	Cost Factors: Systems Integration & Logistics	Component Risks	Non-Program Risks	3% Discount Rate	Range
1. Management Alternative 1 (Storage)[a]	100	75	35	175	385
2. Management Alternative (revised to incorporate Chemical Separation)	100	±15	10	125	200-250
3. Management Alternative 1 (revised to incorporate a New Technology)[b,c]	100	75	35	225	435
4. Target Material	5	5	0	25	35
5. Management Alternative 2	100+	±500	1000	250	350-1850
6. Management Alternative 3	100	±10	150	75	315-335

[a] *It is assumed that risks are the same for dry or wet storage options.*

[b] *It is assumed that risk factors are the same as Management Alternative 1 (Storage).*

[c] *Includes target material.*

management sites, and possibly several new facilities. Technical and procedural bottlenecks could arise in many areas.

2. *Component Risks* - Significant risks exist for specific components of the foreign research reactor spent nuclear fuel program, e.g., the adequacy of the characterization of spent nuclear fuel for interim storage, the methods of spent nuclear fuel disposal, the cost allocation at existing and new facilities, and development of new technology.

3. *Non-Program Risks* - Significant risks exist for components of other programs that affect the implementation of the foreign research reactor spent nuclear fuel EIS, e.g., escalating repository costs, adoption of monitored retrievable storage, and differences in facility utilization plans between this EIS and those of other EISs affecting the Savannah River Site and the Idaho National Engineering Laboratory. For Scenario 5, the risks are that no spent nuclear fuel infrastructure exists in more than half of the eligible countries and that no geologic disposal program exists in most of the eligible countries.

4. *Discount Rate Risks* - Significant risks exist that the discount rate required by the Office of Management and Budget for the year ending February, 1996 (4.9 percent real) will be reduced to a more historically representative level (e.g., 3 percent) in some future annual update. The base case costs for management outside the United States are discounted at a 3 percent rate. The use of a high discount rate is particularly risky because 1) revenues are likely to be fixed (in $/kgTM) early in the program while expenses are variable and uncertain, and 2) revenues received from the reactor operators during the 1996 through 2008 shipping period will almost certainly exceed the costs of management activities during that period. Mathematically, the excess revenues are placed in a trust fund that compounds interest at the discount rate. If the discount rate exceeds the rate at which funds actually compound, then outyear program costs (e.g., disposal) could not be met from the principal and accrued interest in the trust fund. A reduction in the discount rate from 4.9 percent to 3.0 percent has a larger impact on the program than any of the technical or systems integration risks.

F.7.1.4 Potential Total Costs

Table F-122 combines the base case costs with the "other cost factors" to provide a realistic expectation of the potential total costs of the program, excluding escalation. The "other cost factors" are divided into technical factors and discount rate-related factors. This table also shows the cumulative percentage effect on the minimum discounted program costs of real escalation at a rate of 1 percent per year over 40 years.

Table F-122 Potential Total Costs
(Net Present Value, Millions of 1996 Dollars in 1996)

Scenario	*Minimum Program Cost*	*Other Cost Factors (Technical)*	*Other Cost Factors (Discount Rate)*	*Potential Total Cost, No Escalation*	*1% Real Escalation, Cumulative*
1. Management Alternative 1 (Storage)	725/775[a]	210	175	≈1,100	+11%
2. Management Alternative 1 (revised to incorporate chemical separation)	625	85-145	125	≈900	+9%
3. Management Alternative 1 (revised to incorporate a new technology)[c]	625-950	210	225	≈1,050-1,400	10%-11%
5. Management Alternative 2	1250	600-1600	250	2,100-3,100	+13%
6. Management Alternative 3[b]	675	225-275	75	≈1,000	+9%

[a] *Dry/Wet new storage facilities.*

[b] *The total cost risk to the United States is less than 1/2 the total cost risk since a large portion of the activities under this alternative would occur overseas.*

[c] *Includes target material.*

Table F-122 shows that the net present value of the potential total costs of implementing the program in the United States, including an estimate of program risks but excluding escalation, range from about $900 for Scenario 2 to $1.4 billion for Scenario 3.

Costs for storing foreign research reactor spent nuclear fuel overseas are highly speculative. In addition, the overseas storage costs are always higher than the more centralized management alternatives because of the extremely high cost of safely and securely managing and disposing of small quantities of spent nuclear fuel in dozens of countries.

The program costs presented in Tables F-120, F-121, and F-122 are in constant 1996 dollars, discounted to 1996. This implies that funds required to cover these costs are received in 1996 and explicitly or implicitly placed in a trust fund. If payments into the trust fund are deferred, then they must be larger than if they had been received on January 1, 1996. For example, if payments are made in 13 equal annual installments every December 31 over the 1996 through 2008 shipping and receiving period, then the constant-dollar payments must increase by 37 percent. A composite of payment schedules, e.g., 13 years for developed country reactor operators and pay-as-you-go (for the United States) for all other costs, including developing country costs, has the effect of increasing the required constant-dollar payments by as much as 25 to 50 percent.

F.7.1.5 Cost to the United States

The cost of the proposed policy to the United States would depend on the type of financing arrangement that DOE adopts in implementing the policy and the discount rate at which revenues from reactor operators accrue interest. Alternative financing arrangements are discussed in Sections 2.2.1.2 and 2.2.2.3 of the EIS. Briefly, the financing arrangements considered are:

1. United States bears the full cost of the program for developing countries and charges a competitive fee to developed countries.

2. United States bears the full cost for all countries (*no* fee).

3. United States charges a *full-cost-recovery* fee to all countries.

4. United States bears the full cost of the program for developing countries and charges a *full-cost-recovery* fee to developed countries.

From a practical standpoint, the U.S. cost under financing arrangement 3 above would be zero. The issue would be whether any foreign countries would participate in the program if full-cost recovery exceeded a competitive fee. The first and fourth arrangements are functionally similar, the U.S. cost resulting from the difference in the *competitive versus the full-cost-recovery fee.* The U.S. cost under the second arrangement (no fee) would be the total program cost as discussed earlier. Any fees established by the United States will take place pursuant to a Federal Register notice after the Record of Decision for this EIS.

Table F-123 shows costs to the United States for the minimum program in each of the cost scenarios analyzed (except target material) under a variety of fee schedules. Adding target material to Scenarios 1, 2, 5, or 6 would increase the cost by 3 to 4 percent. Fees of $2,000/kgTM, $5,000/kgTM, $7,500/kgTM, and $10,000/kgTM, including a pass-through of shipping charges (all expressed in constant 1996 dollars and levelized over 13 years), are used to provide a range of estimates for the cost to the United States. These fees do not imply that reactor operators would pay them for management in Europe or the United States, or that the fee established by the United States will be one of these values. They are used for illustration only and suggest a bounding range, exclusive of technical risk factors, discount rate adjustments, and escalation. The cost to the United States, presented in Table F-123, is the sum of: 1) the cost of managing the foreign research reactor spent nuclear fuel from the developing countries, including shipping, and 2) the difference between the revenues received for management of developed country foreign research reactor spent nuclear fuel and the total program cost of managing developed country foreign research reactor spent nuclear fuel, excluding shipping. Including shipping in the U.S. management costs allows management costs for the United States and the United Kingdom to be presented on a comparable basis.

Table F-123 shows that for minimum discounted program costs and fees charged to developed country reactor operators levelized over 13 years, costs to the United States for management of foreign research reactor spent nuclear fuel (and target material in Scenario 3) could range from several hundred million dollars at a fee of $2,000/kgTM to a profit for fees of $7,500/kgTM to $10,000/kgTM. The cost of managing the spent nuclear fuel from the developing countries (including shipping) adds roughly $100 million more to the cost borne by the United States. Excluding Scenario 5, for which all costs and fees are speculative, the table shows that costs to the United States in Management Alternative 3 are significantly lower than for Management Alternative 1. The savings to the United States exist because the United States bears none of the cost of Spent Nuclear Fuel Management in Europe except the cost of blending down the HEU at Dounreay.

If fees in the $2,000 to $10,000 per kgTM range (levelized $1996 dollars) are established and charged over 13 years, the costs to the United States would be as estimated in Table F-123 (excluding target materials) plus any additional cost factors not incorporated in the minimum program costs. These additional cost factors are: 1) technical risks, 2) discount rate-related risks, and 3) escalation. Table F-122 shows that

Table F-123 Costs to the United States for the Minimum Program Under Various Scenarios and Fee Structures (Millions of 1996 Dollars, Net Present Value of Costs in 1996, Fees Levelized Over 1996-2008 Period)

Scenario[a]	Full-Cost Recovery[b]	Levelized Shipping Fee $/kgTM	Levelized Management Fee (excluding shipping) $/kgTM	Net Present Value For Levelized Fee[c] (Developed Countries Only)				No Fee[d]	Total (excluding shipping)
				$2,000/ kgTM	$5,000/ kgTM	$7,500/ kgTM	$10,000/ kgTM	Developed Countries	
1. Management Alternative 1 (Storage)	100	1,500	6,500	325	100	(75)	(250)	475	575
2. Management Alternative 1 (revised to incorporate Chemical Separation)	90	1,500	5,800	275	50	(125)	(300)	425	525
3. Management Alternative 1 (revised to incorporate a New Technology)	90-110	1,700	5,600-9,200	275-550	50-325	(150)-125	(325)-(50)	425-700	500-800
5. Management Alternative 2[e]	500+							1,250 +	1,750+
6. Management Alternative 3[f]	85	1,500	6,000	225	75	(50)	(175)	300	375

[a] *The total mass (kgTM) of foreign research reactor spent nuclear fuel in the various scenarios is approximately as follows: Aluminum-based plus TRIGA: 115,000 kgTM; from developing countries: 15,000 kgTM; from developed countries: 100,000 kgTM; to Dounreay in Management Alternative 3: 37,000 kgTM. The total mass of target material is approximately 3,400 kgTM aluminum-based equivalent and essentially all from developed countries.*

[b] *Full-cost recovery from developed countries only. The United States bears the costs of the developing countries in these cases.*

[c] *Net present value of costs to the United States for management fees paid in 13 equal annual installments on December 31 of the years 1996 through 2008. Add costs in column labeled "Full-Cost Recovery" to generate total cost to the United States (developed and developing countries).*

[d] *As above, implicitly paid by the taxpayers in 13 equal annual installments (to maintain consistency with the payment period of the reactor operators), excluding shipping. The net present value of shipping in Scenarios 1 [Management Alternative 1 (Storage)] and 2 [Management Alternative 1 (revised to incorporate chemical separation)] is $140 Million. The net present value of shipping to the United States only in Scenario 6 is $90 Million. The net present value of shipping in Scenario 3 [Management Alternative 1 (revised to incorporate a new technology)] is $160 Million.*

[e] *There is no defined basis for the charges to the United States for non-U.S. management. Costs to the United States under Management Alternative 2 assume that the United States absorbs the cost to construct and operate independent foreign research reactor spent nuclear fuel storage installations (including all supporting safety, security, transport, health physics, etc. infrastructure) for the 22 countries with no commercial nuclear power programs and that the United States partially subsidizes the other countries, depending on developmental status, commercial nuclear power infrastructure, and other factors.*

[f] *U.S. component of Management Alternative 3 only. Revenues paid to the United States exclude shipping charges. Costs to the United States for management in Europe consist only of the charge to blend down the HEU to LEU ($20 million). European reactor operators using Dounreay are assumed to bear all other costs.*

technical risks could add roughly $100 to $200 million to the costs borne by the United States. Discount rate-related risks are of a similar size. Escalation risks are more uncertain but could be in the same range.

F.7.2 Costs of Individual Program Components

This section provides details on program costs for each of the scenarios outlined in section F.7.1.

F.7.2.1 Programmatic Cost Assumptions

Table F-124 shows programmatic assumptions about costs and the basis for the cost calculations.

Table F-124 Programmatic Assumptions and Bases

Variable	*Assumption*	*Basis*
Year Dollars	1996	Standardized to first year of program.
Discount Rate for Management in the United States	4.9 percent real	Required by Office of Management and Budget for programs beginning between February 1995 and February 1996.
Discount Rate for Management in Europe	3.0 percent real	Representative of long-run average in larger Western European economies.
Rounding of Totals	$25 million	Highlights differences between programs that typically differ by $100 million. No implication of precision.
Component Contingencies	Included in base costs	Standard costing assumption
Program Risks	Not included in base costs	Logistical complexity of program could add 10-15 percent to total costs.
Uncertainties	Not included in base costs	
Risk-adjustment	Not included in base costs	
Escalation	Not included in base costs	
Costs incurred over what period	40 years (1996 to 2035) in United States 35 years (1996 to 2020) in United Kingdom	Maximum length of interim storage
Repository Shipping	2030 to 2035 in United States 2025 to 2030 in United Kingdom	Storage maximum in United States and United Kingdom
Qualification of fuel types for disposal	$10M per type allocated to the program, 5 types in program	Idaho National Engineering Laboratory estimate. The foreign research reactor spent nuclear fuel program is estimated to be responsible for three types of aluminum-based spent nuclear fuel and two types of TRIGA spent nuclear fuel. The types are related to the repository program characteristics.

F.7.2.2 Individual Program Components

The proposed foreign research reactor spent nuclear fuel program consists of many components. Table F-125 outlines the components of the five cost analysis scenarios described in Section F.7.1. Detailed discussions of the individual program components follow the table.

F.7.2.3 Logistics and Program Management

Under Management Alternative 1, the United States would undertake a program where the maximum requirements begin with the shipping of an estimated 837 casks of foreign research reactor spent nuclear

Table F-125 Applicability of Specific Cost Components to the Cost Analysis Scenarios

Component	Appendix Section	Management Alternative 1 (Storage)	Management Alternative 1 (revised to incorporate Chemical Separation)	Management Alternative 1 (revised to incorporate a New Technology)	Management Alternative 2	Management Alternative 3	Target Material
Programmatic Assumptions	F.7.2.1	x	x		x	x	x
Logistics and Program Management	F.7.2.3	x	x		x	x	x
Shipping Spent Nuclear Fuel to the United States	F.7.2.4	x	x			x	x
Shipping Spent Nuclear Fuel to the United Kingdom	F.7.2.5				x	x	
Interim Storage at the Savannah River Site	F.7.2.6	x					x
Interim Storage at the Idaho National Engineering Laboratory	F.7.2.7	x	x			x	
Chemical Separation at the Savannah River Site	F.7.2.8		x			x	
New Technology	F.7.2.9			x			x
Reprocessing in the United Kingdom	F.7.2.10				x	x	
High-Level Waste Vitrification and Separation Waste Storage	F.7.2.11		x		x	x	
Disposal of Spent Nuclear Fuel	F.7.2.12	x			x		x
Disposal of Vitrified High-Level Waste	F.7.2.13		x		x	x	
Storage or Reprocessing Overseas	F.7.2.14				x	x	

fuel and 140 casks of target material (977 casks in total) from dozens of ports in 41 countries to as many as 10 ports in the United States and one or more border crossings from Canada. Consistent with the Record of Decision for the Programmatic SNF&INEL Final EIS (DOE, 1995g), aluminum-based foreign research reactor spent nuclear fuel would be delivered to the Savannah River Site and TRIGA foreign research reactor spent nuclear fuel would be delivered to the Idaho National Engineering Laboratory. Approximately 815 casks (including target material) would be shipped to the Savannah River Site and 162 to the Idaho National Engineering Laboratory.

Once the foreign research reactor spent nuclear fuel was in transit to the United States and especially once title had been transferred to the United States, numerous regulations covering safety, health, and environmental compliance would take effect. It is estimated that the direct cost of coordinating shipping, ensuring regulatory compliance, providing program documentation, conducting inspections in the United States and overseas, and providing overall program logistical support is about $5 million per year during the active shipping period (exclusive of shipping costs). This cost would be lower if material is shipped to the United Kingdom (Management Alternative 3). For Management Alternative 1, the discounted cost over the 13-year receipt period in the United States would be approximately $50 million. Costs for logistics and program management during the non-receiving period (years 14 through 40) are assumed to be modest and are accounted for as part of the management costs at the U.S. site.

F.7.2.4 Shipping to the United States

Shipping the foreign research reactor spent nuclear fuel and target material to the United States requires an estimated 977 cask shipments. Of this, 837 cask shipments would contain spent nuclear fuel and 140 cask shipments would contain target material.[4] The shipping period would be thirteen years, beginning in 1996. Discounted total shipping costs to and from the United States are estimated at about $140 million for the spent nuclear fuel and about 10 percent more if target material is included.[5] Under Management Alternative 3, where approximately one-third of the spent nuclear fuel casks are shipped to the United Kingdom, costs for shipping the remaining casks to the United States are about $90 million. Costs include cask rental, inland freight by truck in the United States and overseas, ocean transport to and from the United States (except for shipments from Canada, which would go by truck), port handling, security, insurance, administration, and contingencies. Logistics and program management is described in Section F.7.2.3.

The technical requirements and costs associated with shipping differ depending on the point of origin of the spent nuclear fuel. Costs are estimated separately for seven countries and/or regions of the world: Europe, Australia, Japan, Asia (excluding Australia and Japan), Canada, Other Atlantic, and Other Pacific. This section discusses technical issues associated with shipping the foreign research reactor spent nuclear fuel and target material to the United States from each region.

- **Europe** — European regulations for inland freight and ocean freight shipments of spent nuclear fuel have become very strict in recent years and are virtually certain to become more stringent. Requirements for permits, cross-border shipping, consolidation for ocean shipping, and other factors have driven the cost per cask in an unconsolidated movement to far more than that for inland freight in the United States. Considering the European Community's vessel requirements for the spent nuclear fuel shipped in 1995 under the Urgent Relief Environmental Assessment (DOE, 1994i), it is prudent for costing purposes to assume that shipment by chartered vessel rather than regularly scheduled commercial vessel would be required. (Shipment by purpose-built vessel is not likely to be required.) The cost of chartering a ship capable of carrying spent nuclear fuel casks from Europe to the United States' East Coast and handling the casks at the port and on-board is approximately $400,000. This cost can be spread over a maximum of 6 to 8 casks per vessel. For costing purposes, the EIS assumes 6 casks per vessel and two European ports-of-call. European nations account for an estimated 505 casks, 393 containing aluminum-based spent nuclear fuel, 14 containing target material, and 98 containing TRIGA spent nuclear fuel.

- **Australia** — Australia owns a single, large spent nuclear fuel transportation cask and, thus, does not generate a cask rental charge as part of the spent nuclear fuel program. (A charge for a typical transportation cask is assessed, however, to show true costs to undertake the program.) Australia is unlikely to require chartered shipping. Inland freight charges are moderate. Australia would account for 9 casks, all of which would contain aluminum-based foreign research reactor spent nuclear fuel. For cost analysis, the

4 *The number of casks required for target material could be reduced by more than half if the material was converted to an oxide form prior to shipping. The estimate of 140 casks is based on a conservative estimate of shipping the material as a calcine.*

5 *Shipping target material increases costs much less than proportionately because most of the target material is in Canada.*

Australian cask is assumed to be shipped as part of larger shipments from Asia. These shipments would carry 6 casks per vessel and call on three ports per transit to the United States.

- **Japan** — The Japan Atomic Energy Research Institute owns two casks that would be used for spent nuclear fuel accepted by the United States. Because the Japan Atomic Energy Research Institute is near the port of export for Japan, inland freight charges would be negligible. Japan would likely require chartered vessels (at least as far as Europe for shipments of spent nuclear fuel to the United States via Europe). Shipment by chartered vessel would be approximately $450,000, or $225,000 per cask. It is estimated that Japan would ship approximately 110 casks to the United States (99 aluminum-based and 11 TRIGA). Japan could choose to acquire more casks to reduce its cost per ocean transit. As with Australia, a cask charge is assigned to show true program costs.

- **Asia** (excluding Australia and Japan) — Asian nations (excluding Japan) would be expected to have relatively low inland freight costs. It is unclear if Asian nations would require chartered vessels. Asian nations (excluding Australia and Japan) account for an estimated 62 casks (23 containing aluminum-based spent nuclear fuel, 1 containing target material, and 38 containing TRIGA spent nuclear fuel).

- **Canada** — For cost analysis, all Canadian shipments (approximately 116 casks of aluminum-based spent nuclear fuel and 125 casks of target material) are assumed to come by truck to the Savannah River Site. Cask rental and inland freight charges reflect the shipping times and distances for long overland routes. Shipping by rail is also feasible.

- **Other Atlantic** — All other nations nearer the Atlantic Ocean than the Pacific Ocean are assumed to have characteristics similar to those of Asia (excluding Australia and Japan) but lower ocean shipping costs because of greater proximity to the United States. Shipments from Mexico would come by sea, since the Mexican spent nuclear fuel is located in the southern part of the country. The Other Atlantic nations are not likely to require chartered vessels. Other Atlantic nations account for 38 casks, 23 of which would contain aluminum-based spent nuclear fuel and 15 of which would contain TRIGA spent nuclear fuel.

- **Other Pacific** — All other nations nearer the Pacific Ocean than the Atlantic Ocean are assumed to have characteristics similar to those of Asia (excluding Australia and Japan) but lower ocean shipping costs because of greater proximity to the United States. Because the Other Pacific countries are on the western coast of South America (which is significantly closer to the southeastern United States than the northwestern United States) and because all the spent nuclear fuel from these countries is aluminum-based, the EIS assumes that all shipments from Other Pacific countries will go by sea to an East Coast port via the Panama Canal. The Other Pacific nations would not be likely to require chartered vessels. Other Pacific nations account for 12 casks, all of which would contain aluminum-based spent nuclear fuel.

Table F-126 summarizes the cost of shipping a single spent nuclear fuel cask from various parts of the world to the United States in the configuration considered most likely by this EIS. The base case assumes the use of charter ships. The discounted cost of overseas shipping to the United States (including overland shipping from Canada and including target material) is shown in the table as $158 million (summing the bottom row). Of the 977 shipments, 827 originate either in Canada or in ports nearer the U.S. East Coast

Table F-126 Representative Shipping Costs to/from the United States for a Spent Nuclear Fuel Cask (Thousands of 1996 Dollars per Cask and Millions of 1996 Dollars for the Program, including Target Material)

Activity/Cost	*Europe*	*Australia*	*Japan*	*Other Asia*	*Canada*	*Other Atlantic*	*Other Pacific*
Charter	Y	Y	Y	Y	N/A	Y	Y
U.S. Coast	East	West	West	West	N/A	East	East
Charter Cost $k	400	550	550	500	N/A	300	300
Casks/Charter	6	See Other Asia	6	6	N/A	6	6
Ports-of-Call	2	See Other Asia	1	3	N/A	3	3
Total Rental Charges, $k/Cask	51	48	42	66	21	60	66
Inland Freight, Country, Site, and Overland Route Weighted, $k/Cask	37	38	41	30	25	26	38
Insurance, Security, Administration, Cask Return, $k/Cask	51	49	58	70	36	49	49
$k/Cask, Excluding Contingency	224	253	239	246	86	232	246
Number of Casks (Aluminum)	393	9	99	23	116	23	12
Number of Casks (TRIGA)	98	0	11	38	0	15	0
Number of Casks (Target Material)	14	0	0	1	125	0	0
Number of Casks (Total)	505	9	110	62	241	38	12
of which, from Developing Countries	72	0	0	53	0	38	12
Total Cost, including 15% Contingency, $M	130	2	30	18	24	10	3
Discounted Cost ($M)	95	2	22	13	17	7	2

(including 12 cask shipments from the West Coast of South America). The remaining 150 cask shipments originate in ports nearer the U.S. West Coast. Assuming shipments to the nearest U.S. coast, regardless of the type of spent nuclear fuel, an estimated 113 shipments of TRIGA spent nuclear fuel received at East Coast ports and an estimated 132 shipments of aluminum-based spent nuclear fuel received at West Coast ports would be shipped overland to the appropriate management site. Key issues in analyzing shipping costs follow the table.

- **Use of Chartered Ships** - Chartered vessels are used for conservatism in costing. The cost increase from using charters rather than regularly scheduled commercial vessels (for those countries likely to permit shipping by regularly scheduled commercial liners) is approximately $10 million. Europe and Japan would require charters in any case. Canada would transport by land. These three regions/countries account for more than 80 percent of the proposed shipments. No additional port-related costs are assigned if military ports are used.

- **Casks Per Ocean Shipment** - The costs in Table F-126 assume that European and Japanese shipments are made by a chartered vessel carrying six casks consolidated at two ports in Europe and one in Japan. For Japan, this charter loading implies the acquisition of more casks or the use of commercial casks. The nine casks (total) from Australia are assumed to be part of larger shipments from Asia. Even though Japan and Australia would most likely use their own casks, a cask rental charge is shown to reflect true program costs regardless of where the costs are borne and to reflect the likely requirement for new casks by Japan. Reducing the number of casks per shipment from Japan increases shipping costs by $20 million.

Shipments from the rest of the world (excluding Europe and Canada) are assumed by charter at the rate of 6 casks per vessel and 3 ports-of-call (i.e., two casks per country). Adding ports-of-call increases costs in transit (by about $20,000 per port-of-call and $20,000 per day in transit between ports) but saves money on balance by increasing the number of casks on the ship. Reducing the shipments from Asia (excluding Australia, Japan) and the Other Atlantic and Other Pacific countries to 2 casks and 1 port-of-call would increase program costs by $12 million.

- **Shipping to Distant Coasts and Sites** -- The cost of shipping the foreign research reactor spent nuclear fuel depends on which ports were selected and from where they would be accepting the shipments. The dynamics of the program are that roughly 75 percent of the foreign research reactor spent nuclear fuel is aluminum-based (and therefore would be destined for the Savannah River Site, on the United States' East Coast) and roughly 75 percent of the foreign research reactor spent nuclear fuel (excluding Canadian spent nuclear fuel) is in countries on the Atlantic side of the United States. While the 75 percent aluminum-based spent nuclear fuel and the 75 percent Atlantic spent nuclear fuel are not identical, there is sufficient overlap to create a situation where shipping all the spent nuclear fuel directly to a United States East Coast port and then distributing the TRIGA spent nuclear fuel to the Idaho National Engineering Laboratory by land would be only about 5 percent ($8 million) more expensive than shipping the spent nuclear fuel to the nearest port and then overland to the appropriate site. The cost of overland shipping by truck from an eastern port to the Idaho National Engineering Laboratory for a shipment that would logically arrive at an eastern port is less than the cost of ocean shipping to a western port to minimize the overland transit by truck.

- **Receipt Rates at the Savannah River Site and the Idaho National Engineering Laboratory** -- To accept all the foreign research reactor spent nuclear fuel within the proposed 13-year period requires, on average, cask receipts of almost six casks per month (seven per month if target material is included). Splitting the spent nuclear fuel by fuel type, consistent with the Record of Decision for the Programmatic SNF&INEL Final EIS (DOE, 1995g), implies receipt of 4 to 5 casks per month of aluminum-based spent nuclear fuel at the Savannah River Site and about one cask per month of TRIGA spent nuclear fuel at the Idaho National Engineering Laboratory.[6] About 1 cask per month of target material would also be received at the Savannah River Site.

- **Cask Rental Charges** -- Truck casks rent for approximately $1,500 per day on long-term lease. Shorter-term rentals are appreciably more expensive (EG&G, 1994b). Table F-126 incorporates the $1,500 per day rate for a long-term lease. The use of the smaller truck casks (compared to rail casks) permits savings in ocean shipping, short overland transport (although this could change in response to high charter costs), and security. The cost to acquire a new truck cask has been increasing steadily and is now approaching $2 million. The time from ordering to delivery exceeds 1 year. Because of the limited market for casks and the risk of constructing a cask for which there is no long-term demand, potential cask owners and lessors would place a high fixed charge rate on an investment in new casks for the foreign research reactor program. For a 20-year operating life, the fixed

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6 *The weighted-average number of spent nuclear fuel elements per cask is estimated to be slightly more than 27. The sites are limited by cask receipt rates, not elements per cask. Some casks would have as many as 120 elements. Others would have one element. Most would have about 27 to 30 elements.*

charge rate would be at least 30 percent. For a fixed charge rate of 30 percent, a $2 million cask must rent for $600,000 per year, or approximately $1,650 per day on a yearly lease.

- **Cask Shipment and Rental Periods** -- The average time required to complete a round-trip shipment depends on the area of cask origin, the number of casks shipped at one time, the number of ports-of-call made enroute to the United States, inland shipping in the United States, and turnaround time at the sites. Excluding Canada, round-trip cask shipment periods range from an average of less than 40 days for a cask from the Atlantic coast of South America to the southeast coast of the United States (with an ultimate destination of the Savannah River Site) to more than 60 days for a cask from Australia to the same ultimate destination (either via a Pacific port and an overland transit to the Savannah River Site or via a passage through the Panama Canal to an Atlantic Port).

The base costs cover two ocean transits, port handling in two countries, shipment to and from the cask lessor, and overland transport from the ports to and from the sites and reactor facilities. Cask handling at the sites is estimated separately.

- **Contingencies** -- Over the past few years, the cost of almost all phases of international spent nuclear fuel shipping has risen sharply. Also, European regulations regarding ocean shipping of nuclear cargoes have tightened dramatically. While these costs are built into the values in Table F-126, potentially large additional contingencies are not. These contingencies include escalating cask lease rates; partially filled casks; higher inland freight charges in the United States; dedicated rail shipping in the United States; consolidation limitations in Asia, South America, or Africa; and additional security. On the other hand, the single largest contingency -- the use of charter ships -- has been added to the base case. Consideration of the magnitude of the contingencies suggests a contingency factor of about 15 percent. This factor applies to the shipping component of the program only, not the impacts on the program logistics or integration from delays in shipping, barriers erected by the States, etc. These program-level impacts are discussed separately in Section F.7.4.

F.7.2.5 Shipping to the United Kingdom

Shipping to the United Kingdom is less expensive than shipping to the United States. Cost estimates provided by the United Kingdom Atomic Energy Authority for this EIS are about $30,000 per cask from Europe (Scullion, 1995). This compares to more than $200,000 per cask estimated for shipments from Europe to the United States. The estimates for shipping to the United Kingdom reflect the large savings from the very short ocean transit from continental Europe (and thus the vessel charter cost), the ocean transit and site turn-around periods (and thus the cask rental time), the inland freight charges for shipping a short distance in the United Kingdom, and the reduced administrative, insurance, and security costs for the shorter activity.

It is possible that the estimated cost for shipments to the United Kingdom is understated in comparison to the U.S. costs for at least two reasons. First, no detailed analysis of the cost components similar to that in Table F-126 was conducted and thus some costs, especially indirect costs, such as administration, may have been omitted. Second, costs for shipments to the United States have increased sharply in recent years. Costs for recent shipments to the United States were higher than anticipated and may not be reflected in the estimated costs to ship from Europe to the United Kingdom.

F.7.2.6 Storage at the Savannah River Site

Consistent with the Record of Decision for the Programmatic SNF&INEL Final EIS (DOE, 1995g), approximately 17,800 aluminum-based spent nuclear fuel elements could be received and managed at the Savannah River Site. These elements would be stored or chemically separated. Under Implementation Alternative 1c to Management Alternative 1, target material equal to about 600 aluminum-based elements could also be received and stored at the Savannah River Site. The cost to receive and store the target material is proportional to the ratio of target material (expressed in element-equivalents, e.g., cans) to spent nuclear fuel elements (i.e., about 3.4 percent). Costs in this section refer to the basic implementation of Management Alternative 1 (17,800 spent nuclear fuel elements and no targets).

Storage at the Savannah River Site would consist of two phases: Phase-1 storage in existing facilities and Phase-2 storage in new facilities. Logistically, the base case for Management Alternative 1 (storage) is as follows:

- At the start of the implementation period, aluminum-based spent nuclear fuel would be shipped to the Savannah River Site and wet-stored in RBOF and the L-Reactor disassembly basin.
- At about the same time, construction would begin on a staging and characterization facility and an interim dry or wet storage facility at the Savannah River Site. The staging facility would be designed to receive and transfer all the foreign research reactor spent nuclear fuel (and other nuclear materials, including domestic research reactor spent nuclear fuels). The dry or wet storage facility would be designed to store the spent nuclear fuel (and possibly target material) until the spent nuclear fuel and target material were prepared for shipment to the repository. The new facilities would be commissioned in 2003, accept off-site receipts of foreign research reactor spent nuclear fuel through 2008, and on-site transfers (of all aluminum-based materials, not just foreign research reactor spent nuclear fuel) from the RBOF and the L-Reactor disassembly basin through about 2008 or 2009. If commissioning of the new storage facility is delayed to 2005, transfers from existing basins would continue through about 2010.
- At some point in the 2015 to 2035 time period, the stored spent nuclear fuel would be prepared for repository disposal in as-yet unspecified repository-qualified canisters. Cost estimates are based on a repository packaging and shipping period of 2030 to 2035.

Table F-127 shows the annual costs for storage of 17,800 foreign research reactor spent nuclear fuel elements at the Savannah River Site during Phase 1 and Phase 2, where Phase 2 storage is dry (WSRC, 1995c). Receiving and storing target material would add $20 million (discounted) to expenditures at the Savannah River Site and $35 million (discounted) to the total costs. The key assumptions used to generate the costs in Table F-127 are discussed below.

- Annual operating costs for round-the-clock operations at RBOF and L-Reactor disassembly basin are allocated to the foreign research reactor spent nuclear fuel program in proportion to the share of foreign research reactor spent nuclear fuel mass transferred to or from the basins relative to total cask transfers at RBOF, and L-Reactor disassembly basin in each year until all of the foreign research reactor spent nuclear fuel has been transferred to dry storage (about 2008 or 2009). Unit costs are assumed fixed in each year. Thus, allocable costs scale in proportion to the amount of foreign research reactor material received at the basins.

Table F-127 Storage of Aluminum-Based Spent Nuclear Fuel at the Savannah River Site, Including Phase 2 Dry Storage (Millions of 1996 Dollars)

Year	*Basin Costs*	*Capital Costs-Staging*	*Operating Costs-Staging*	*Capital Costs-Storage Facility*	*Capital Costs-Storage Canisters*	*Operating Costs-Storage Site*	*Decontamination & Decommissioning*
1996	16	1					
1997	20	5					
1998	23	5					
1999	24	6		1			
2000	21	18		1			
2001	15	22		2			
2002	15	24		2			
2003	15	5	3	1	9	3	
2004	15		3	1	9	3	
2005	19		3	1	9	3	
2006	16		3	1	9	3	
2007	16		3	1	9	3	
2008	16		3	1	9	3	
2009	6	1	3	1		3	
2010		1	1			3	
2011		4	1			2	
2012		4	1			2	
2013		3	1			2	
2014		2	1			2	
2015-2029			1/yr.			2/yr.	
2030-2034			3/yr.			3/yr.	
2035			3			3	9
Total Costs (Undiscounted)	238	103	65	14	55	77	9
NPV	174	74	23	9	34	28	1

- A staging facility would be constructed for operation in 2003 (although it could be deferred until 2005). The primary functions of the staging facility would be to: 1) accept on-site transfers and off-site receipts, 2) characterize the spent nuclear fuel, 3) transfer the spent nuclear fuel from the received casks to interim dry or wet storage, and 4) transfer the spent nuclear fuel from interim dry or wet storage to repository-qualified canisters. If processing of the spent nuclear fuel prior to disposal were required, e.g., melting and diluting the material, additional facilities would be added to the staging facility.

  Excluding a melt-and-dilute facility, the staging facility is estimated to have a discounted cost of $150 million. Because the foreign research reactor spent nuclear fuel program would share the facility with other programs, costs are allocated to the foreign research reactor spent nuclear fuel program in proportion to the average of: 1) foreign research reactor spent nuclear fuel to other spent nuclear fuel received and staged to dry or wet storage over the period of facility operations (2003 through 2035), and 2) foreign research reactor spent nuclear fuel to other spent nuclear fuel staged from storage to repository casks over the period of facility operations. Using this approach, about 43 percent of the capital and operating costs of the facility would be allocable to the foreign research reactor spent nuclear fuel program. Foreign research reactor spent nuclear fuel represents about 57 percent of the total aluminum-based spent nuclear fuel to be managed at the Savannah

River Site over the 1996 through 2035 period (by MTR-equivalents) but only 28 percent of the total aluminum-based spent nuclear fuel received initially at the new staging and characterization facility. The unweighted average of these two percentages is 43 percent. Because most of the foreign research reactor spent nuclear fuel arrives prior to the operation of the new staging and characterization facility, the foreign research reactor spent nuclear fuel bears a disproportionately high share of the operating costs of RBOF and L-Reactor disassembly basin and a disproportionately low share of the capital and operating costs of the new staging and characterization facility.

- A new dry or wet storage facility would be constructed for operation in 2003. A dry storage facility would consist of a pad, fence, canisters, and storage overpacks. It would operate through 2035. The canisters used at the dry facility would not necessarily be qualified for repository disposal. During the storage phase, the canisters would be loaded with approximately 228 elements apiece.[7]

For cost analysis, the spent nuclear fuel is assumed to be taken out of storage over the period 2030 through 2035 for transfer to repository-qualified canisters. The actual timing of the transfers could be earlier but cannot be specified at present. The undiscounted cost of the facility per canister is $530,000 for the canister itself, $110,000 for the storage overpack, and $10,000 for a share of the pad (Stroupe, 1995). Undiscounted fixed costs for the facility, about 57 percent of which would be allocable to the foreign research reactor spent nuclear fuel program, include $24 million for security fencing, other fixed facility costs, licensing, etc.

It is estimated that about 57 percent of the $100 million discounted cost of a wet storage pool constructed from 1996 through 2002 would be allocated to the foreign research reactor spent nuclear fuel program.

Operations and maintenance and safeguards and security costs of about $3.2 million per year are allocated about 57 percent to the foreign research reactor spent nuclear fuel program (WSRC, 1995c). For the wet storage pool, operations and maintenance costs are about $5 million per year higher than at the dry facility. These costs are also allocated about 57 percent to the foreign research reactor spent nuclear fuel program.

The net present value of the allocated expenditures to receive and dry-store the aluminum-based spent nuclear fuel at the Savannah River Site is the sum of the net present values on the bottom row of Table F-127 or about $350 million for dry storage (and about $400 million for wet storage, not shown). Additional expenditures at the Savannah River Site would be incurred to receive and store target material ($20 million) and qualify the aluminum-based spent nuclear fuel for the repository ($25 million). The site-specific components of the other cost factors described in Section F.7.4 (e.g., additional characterization requirements, materials processing prior to repository packaging) would also be extra.

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7 *Aluminum-based elements can be related according to equivalent MTR elements. The precise loading level is 255 MTR-equivalent elements. Excluding the RHF elements from France, the average aluminum-based foreign research reactor spent nuclear fuel element is equal to 1.12 MTR-equivalents. RHF elements are rated at 20 MTR-equivalents each. The weighted-average MTR-equivalent from the MTR type elements and RHF elements is 21,400. The mass of aluminum-based elements is 101,300 kgTM. This value is based on 85 RHF elements at 110 kg (243 lb) each, 2,650 NRU elements (from Canada) at 5.7 kg (12.6 lb) each, and 15,064 MTR-type elements at 5.1 kg (11.2 lb) each. Target material is excluded from these calculations. Including target material would increase the total to 104,700 kgTM excluding the can.*

F.7.2.7 Storage at the Idaho National Engineering Laboratory

In the base scenarios involving United States acceptance of foreign research reactor spent nuclear fuel, approximately 4,900 TRIGA elements would be shipped to the Idaho National Engineering Laboratory for storage in existing facilities.

The Idaho National Engineering Laboratory would store the TRIGA spent nuclear fuel in the IFSF until the spent nuclear fuel was transferred to canisters for shipping to the repository. Table F-128 shows annual operating costs for the Idaho National Engineering Laboratory to dry-store approximately 4,900 TRIGA elements at the IFSF. (The Idaho National Engineering Laboratory could also wet-store the TRIGA elements at the FAST facility for about twice the cost as at IFSF.) The discounted total cost using the IFSF facility for storage is approximately $30 million. Qualification of TRIGA spent nuclear fuel for repository disposal would add another $15 million.

To complete the transfers from existing storage facilities to repository-qualified dry storage canisters, the Idaho National Engineering Laboratory might eventually require a new staging facility similar to that at the Savannah River Site. The Idaho National Engineering Laboratory is deferring construction of this facility until the repository waste acceptance criteria are available some time after 2000. Based on the share of TRIGA spent nuclear fuel relative to all material to be dry-stored at the Idaho National Engineering Laboratory and geologically disposed, the foreign research reactor spent nuclear fuel program would be allocated no more than $10 million of the capital cost of a staging facility whose discounted total cost would be less than $150 million. Allocable operating costs would be the same as shown in the column for repository canister loading. For cost analysis, repository loading and shipping is assumed to take place in 2030. Actual loading could take place earlier but cannot be specified at present.

F.7.2.8 Chemical Separation at the Savannah River Site

Implementation of Management Alternative 1 (revised to incorporate chemical separation) at the Savannah River Site could take place in different ways. One bounding case is to assume that existing and new facilities are used in essentially the same way as in Management Alternative 1 (storage). RBOF and L-Reactor disassembly basin are used for receiving and lag-storage, a new staging and characterization facility is required for repository loading of aluminum-based material received after the completion of chemical separation operations, one of the Canyons (F- or H-Canyon) is used at a moderate rate, new dry or wet storage facilities are required, etc. This option can be viewed as the separation of foreign research reactor spent nuclear fuel within a larger program to store and directly dispose non-foreign aluminum-based spent nuclear fuel.

The other bounding case can be viewed as the separation of foreign research reactor spent nuclear fuel within an accelerated program to chemically separate all of the accumulated aluminum-based materials and medium-term receipts. In this case, RBOF continues to be used for 40 years for receipts, characterization, storage and repository loading; no new staging and characterization facility is constructed; receipts of aluminum-based spent nuclear fuel from domestic sources are accelerated; one of the Canyons (F- or H-Canyon) is used at an accelerated pace; and no new dry or wet storage facilities are required.

In either case, chemical separation continues to around 2008 to 2010, at which point the canyons are shut down. In the first case, however, enough material remains on site and due to be received that a large-scale storage program (including a new staging and characterization facility) is required. In the second case, very little separable material remains on site and only about 5 casks per year are due to be received at the

Table F-128 Storage of TRIGA Spent Nuclear Fuel at the Idaho National Engineering Laboratory (Millions of 1996 Dollars)

Year	*Capital Costs -Staging*	*Transfers*	*IFSF Operations*	*Repository Canister Loading*	*Repository Canisters*	*Operations & Maintenance*	*Decontamination &Decommissioning*
1996		.4	1				
1997	1	.4	1				
1998		.4	1				
1999		.4	1				
2000		.4	1				
2001		.4	1				
2002		.4	1				
2003		.4	1				
2004		.4	1				
2005		.4	1				
2006		.4	1				
2007		.4	1				
2008		.4	1				
2009			1				
2010			1				
2011			1				
2012			1				
2013	3		1				
2014	4		1				
2015	3		1				
2016-2029			1/yr.				
2030			1	5	10	.1/yr	
2031-2035							2
Total Costs (Undiscounted)	11	5	35	5	10	4	2
NPV	5	4	17	1	2	2	0

time the Canyons are shut down. In this latter case, existing facilities can handle all program functions, including repository canister loading.

The first case is used for cost analysis purposes in this Appendix. This case is more probable, since it is more conservative with respect to selection of separation as an alternative and more conservative with respect to costs.

In either case, uranium (but not plutonium) is chemically separated from fission products at one of the canyons at the Savannah River Site.[8] In this EIS, costs for operations at F-Canyon are used since they are slightly higher than costs at H-Canyon (about $25 million). The credit for recovered uranium is the same in either case.

For either Management Alternative 1 (revised to incorporate chemical separation) (17,800 elements) or Management Alternative 3 (12,200 elements), the following assumptions apply:

8 *HEU cannot be chemically separated from LEU. Plutonium can be chemically separated from uranium and fission products but it is not the intention of the Savannah River Site or this EIS to do so. The amount of plutonium in the foreign research reactor spent nuclear fuel is negligible.*

- Basin operations continue until all material can be transferred out of the basins to the Canyons. Foreign research reactor spent nuclear fuel is out of the basins in 2006 under Management Alternative 1 (revised to incorporate chemical separation) and 2005 under Management Alternative 3. From 2003 forward, all receipts take place at the new staging and characterization facility.

- Canyon operations would take place over a maximum of 13 years (1998 through 2010). Actual operations could be completed by about 2009 under Management Alternative 1 (revised to incorporate chemical separation) and as soon as the final shipments were received under Management Alternative 3. The selection of a canyon or canyons will be specified in the Interim Management of Nuclear Materials EIS (DOE, 1995b) and a facilities utilization study currently in process at the Savannah River Site. If no processing is selected in either of those studies, none will be selected for foreign research reactor spent nuclear fuels.

- All Canyon operations that apply to foreign research reactor spent nuclear fuel apply to other, similar materials at the Savannah River Site, i.e., domestic research reactor spent nuclear fuel and DOE and government aluminum-based spent nuclear fuel. Canyon capacity is shared according to the MTR-equivalents of material in each category (foreign and non-foreign) on-site in each year.

- All spent nuclear fuel would be separated incrementally to at-risk materials under the Interim Management of Nuclear Materials EIS (DOE, 1995b).[9] Processing of at-risk materials would be completed in 2002 or early 2003. Spare dissolver capacity would be available for aluminum-based spent nuclear fuels at a rate of 720 MTR-equivalents in 1998 and 1999 and 2880 MTR-equivalents thereafter. Aluminum-based spent nuclear fuel could be separated incrementally over the period 1998 through 2002 or early 2003. Costs (at F- and H-Canyon) for all aluminum-based spent nuclear fuels would be $10.4 million in 1996, $13 million in 1997, $18 million in 1998 and 1999, $5 million in 2000, $3 million in 2001, $13 million in 2002, and $32 million per year thereafter.

- Recovered HEU is blended down to LEU for sale to a commercial power reactor operator. The value of the LEU is assumed to be 85 percent of the value of fresh LEU for power reactors. A value of $5,000 per MTR-equivalent is used for the sales revenue.

- A penalty is assessed on any programs that defer phasedown of Canyon operations beyond the point that the Canyon would be "deinventoried." At some point after 2002, separation of research reactor aluminum-based spent nuclear fuel may become the final base mission at a Canyon. If so, continued operations would incur a deferral penalty estimated at $11 million in the first year of deferral, $22 million in the second year, and $33 million per year thereafter.[10]

Table F-129 shows the costs allocated to the foreign research reactor spent nuclear fuel program for activities at the Savannah River Site under Management Alternative 1 (revised to incorporate chemical

9 *At-risk materials are materials that require stabilization through processing to ensure long-term safety and security.*

10 *A further penalty for deferring "deactivation" is not assessed. The Savannah River Site does not believe that continued operations through about 2008 to 2010 will defer the transition from deinventoried status to deactivated status.*

Table F-129 Chemical Separation Costs at the Savannah River Site Under Management Alternative 1 (Revised to Incorporate Chemical Separation)

Year	*Allocated Receiving, Lag Storage, Facilities Support*	*Spare Dissolver Capacity (MTR-equivalents)*	*Approximate Foreign Research Reactor Share of Dissolver (percent)*	*Allocated Canyon Operations Cost*	*Allocated Canyon Deferral Penalty*	*Allocated HEU Credit*
1996	16	0				
1997	22	0				
1998	25	720	72	13		3
1999	26	720	72	13		3
2000	27	2880	72	4		10
2001	22	2880	72	2		10
2002	23	2880	72	10		10
2003	17	2880	72	23	8	10
2004	16	2880	72	23	16	10
2005	19	2880	72	23	24	10
2006	8	2880	72	23	24	10
2007	0	2880	72	23	24	10
2008	1	2880	72	23	24	10
2009	1	2880	60	19	20	9
2010	1	2880	0	21	20	3
2011-2035	0-2/yr.					
Total Costs (Undiscounted)	242			199	139	107
NPV	178			127	81	70

separation). The foreign research reactor spent nuclear fuel program incurs costs at the percentage shown in the fourth column. This percentage is approximately the spare dissolver capacity allocated to the foreign research reactor program in each year. The change in the percentage at the end occurs because less than proportional dissolver capacity is required to complete the foreign research reactor spent nuclear fuel processing.

Table F-130 shows the same information as Table F-129, adjusted for the shipment of 5,600 aluminum-based elements to Dounreay, Scotland (Management Alternative 3). Table F-130 shows significant cost reductions at the Savannah River Site for basin operations (and related non-processing activities). Separation operations are shown ending in 2007 even though receipts continue through 2008. This is a function of the dissolver capacity available through 2010 and the reduced quantity of foreign research reactor spent nuclear fuel at the Savannah River Site under Management Alternative 3. As a practical matter, the cost impact of stretching out the processing through 2008 is insignificant.

Expenditures at the Savannah River Site for receiving and storing the target material and at the Idaho National Engineering Laboratory for receiving and storing the TRIGA spent nuclear fuel are the same as in the Management Alternative 1 (storage). These values are about $20 million (out of a total of about $35 million) and $50 million, respectively.

F.7.2.9 New Technology

Under Implementation Alternative 7 of Management Alternative 1 (discussed in Section 2.2.2.7 of the EIS), DOE would initiate a development program to select a new treatment and/or packaging technology

Table F-130 Chemical Separation Costs at the Savannah River Site Under Management Alternative 3

Year	*Allocated Receiving, Lag Storage, Facilities Support*	*Spare Dissolver Capacity (MTR-equivalents)*	*Approximate Foreign Research Reactor Share of Dissolver Capacity (Percent)*	*Allocated Canyon Operations Cost*	*Allocated Canyon Deferral Penalty*	*Allocated HEU Credit*
1996	12	0				
1997	17	0				
1998	20	720	62	11		
1999	22	720	62	11		2
2000	22	2880	62	3		2
2001	16	2880	62	2		9
2002	16	2880	62	8		9
2003	13	2880	62	20	7	9
2004	11	2880	62	20	14	9
2005	7	2880	62	20	20	9
2006	0	2880	62	20	20	9
2007	0	2880	6	2	2	1
2008	0	2880	0	0	0	0
2009	0	2880	0	0	0	0
2010	0	2880	0	0	0	0
2011-2035	.1-.5/yr.					
Total Costs (Undiscounted)	173			117	63	68
NPV	129			80	39	47

which would then be constructed and operated to manage the foreign research reactor fuel. A number of different technologies will be considered before one or more are selected for further development.

In addition to the uncertainty as to which technology(ies) will be chosen, there are other cost uncertainties including: the repository disposal fee, the need for new facilities and the requirements needed for managing domestic fuel. To account for these uncertainties, a range of costs have been developed. The costs range from about $950 million (undiscounted) or $625 million (discounted) to about $1.75 billion (undiscounted) or $950 million (discounted).

F.7.2.10 Reprocessing in the United Kingdom

Under Management Alternative 3, approximately 5,600 aluminum-based spent nuclear fuel elements would be shipped to the United Kingdom Atomic Energy Authority's facility at Dounreay, Scotland for reprocessing.[11] The remaining 12,200 aluminum-based elements would be chemically separated at the Savannah River Site (Section F.7.2.8).[12] The TRIGA spent nuclear fuel would be stored at the Idaho National Engineering Laboratory (Section F.7.2.7).

11 Equal to about 7,900 MTR-equivalents, including 85 RHF elements at 20 MTR-equivalents apiece.

12 Equal to about 13,600 MTR-equivalents, including the 2,650 Canadian NRU elements and all other elements (excluding the French RHF elements) at 1.12 MTR- equivalents apiece.

The number of elements to be reprocessed at Dounreay is based on the number of spent nuclear fuel elements in countries with commercial nuclear power programs and the clear capability to manage the reprocessing wastes.[13] The reprocessing waste from Dounreay is returned to the countries of origin. More generally, Management Alternative 3 can be viewed as chemical separation of approximately 2/3 of the aluminum-based foreign research reactor spent nuclear fuel elements in the United States and 1/3 in the United Kingdom.

Table F-131 shows the United Kingdom Atomic Energy Authority's currently estimated costs to reprocess aluminum-based spent nuclear fuel elements. The cost for conversion assumes a downblending ratio of 2:1 (i.e., one unit of depleted uranium at 0 percent enrichment is added to each unit of separated uranium at 40 percent enrichment to produce two units of uranium at 20 percent enrichment). The costs in Table F-131 are converted from British Pounds to United States Dollars at a rate of 1.55 dollars per pound. Using these costs, the discounted cost to ship, receive, reprocess, and dispose of the wastes from 5,600 aluminum-based spent nuclear fuel elements on a schedule similar to that at the Savannah River Site and to obtain LEU metal fuel is approximately $265 million. At a discount rate of 3 percent, this is equivalent to about $7,000/kgTM, including a charge of about $700/kgTM for blending down the separated HEU to LEU.

Table F-131 Costs at Dounreay (1996 Dollars)

Activity	*Cost*
Transport Casks to/from Dounreay	$31,000/cask @ 2 casks per shipment
Receive & Unload Casks	$7,700/cask
Reprocess and produce cementous intermediate-level waste	$5,750/kgTM (HEU only)
Convert Uranyl Nitrate to Metal	$4,500/kg uranium metal (or $2,800/kg UO_2 for oxide)
Value of Metallic Uranium	$15,000/kg uranium
Store U-235	$1,550/kg U-235
Store intermediate-level waste	$1,550 per 500 l (132 gal) drum per year (containing 10 kg (22 lb) of spent nuclear fuel wastes)
Transport intermediate-level waste to originating country	$2,600/drum
Geologic disposal of intermediate-level waste	$31,000/drum

Source: All Costs (except value of metallic uranium) (Scullion, 1995).

Foreign research reactor operators may prefer to view their costs as the sum of the undiscounted current costs for shipping, reprocessing, and uranyl nitrate conversion to metal (without downblending to LEU) plus the discounted costs for interim storage of uranium, interim storage of reprocessing waste, and geologic disposal of reprocessing waste. Assuming a 3 percent discount rate for the outyear costs, and excluding the value of recovered metal uranium, the reactor operator would estimate a current cost of about $9,500/kgTM, excluding the value of the recovered uranium and $7,200/kgTM including the value of the recovered uranium. At a zero percent discount rate, which is reasonable if the reactor operator wants to incorporate a risk-adjustment for long-term unknowns like geologic disposal, the current costs are about $12,700/kgTM. The value of recovered metal HEU is credited to Dounreay to make it consistent with the value of the recovered LEU at the Savannah River Site. Blend-down at Dounreay would cost about $700/kgTM on a current cost basis. Since these cost estimates are based on current costs (i.e., 1996 dollars in 1996) rather than the current fraction of a series of costs (i.e., 1/13 of 13 years' worth of constant costs over the 1996 through 2008 period at the Savannah River Site), they are exposed to escalation.

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13 Belgium, France, Germany, Italy, Spain, Switzerland, United Kingdom.

In comparing these costs to costs for managing the spent nuclear fuel in the United States, the key technical differences the reactor operator sees are: 1) receipt of converted fresh metal (with or without downblending), and 2) receipt of cementous waste. How the reactor operator prices receipt of the waste product compared to the charge estimated by the United Kingdom Atomic Energy Authority would have a major impact on the attractiveness of doing business with the United Kingdom versus the United States.

Table F-132 shows the annual cash flows from the European component of Management Alternative 3, including downblending to LEU. Escalation is not included in Table F-132. Net present value is calculated at a 3 percent real discount rate.

Table F-132 Annual Cash Flows from Europe Under Management Alternative 3 (Dollars in Millions)

Year	*Shipping & Receipt*	*Reprocessing*	*Conversion*	*Product Value*[a]	*Store U-235*	*Store Intermediate - Level Waste*	*Transport Intermediate- Level Waste*	*Dispose of Intemediate - Level Waste*
1996	.7	16.6	3.8	6.5	.1	0	0	0
1997	.7	16.6	3.8	6.5	.1	0	0	0
1998	.7	16.6	3.8	6.5	.1	0	0	0
1999	.7	16.6	3.8	6.5	.1	.8	0	0
2000	.7	16.6	3.8	6.5	.1	1.2	0	0
2001	.7	16.6	3.8	6.5	.1	1.5	0	0
2002	.7	16.6	3.8	6.5	.1	1.9	0	0
2003	.7	16.6	3.8	6.5	.1	2.3	0	0
2004	.7	16.6	3.8	6.5	.1	2.7	0	0
2005	.7	16.6	3.8	6.5	.1	3.1	0	0
2006	.7	16.6	3.8	6.5	.1	3.5	0	0
2007	.7	16.6	3.8	6.5	.1	3.8	0	0
2008	.7	16.6	3.8	6.5	.1	4.2	0	0
2009-2025	0	0	0	0	0	4.2/yr	0	0
2026-2030	0	0	0	0	0	0	1.4/yr	16.6/yr
Total Cash Flows (Undiscounted)	10	215	49	84	2	118	8	100
NPV	8	176	40	69	1	65	3	38

[a] *Cost Savings*

F.7.2.11 High-level Waste Vitrification and Separation Waste Storage

The chemical separation operations at the Savannah River Site generate low-level waste and high-level waste that must be managed. Low-level waste is converted to a saltstone material and stored on-site. High-level waste is converted into a borosilicate glass log (vitrification) at the Defense Waste Processing Facility. Costs for the Defense Waste Processing Facility function, including low-level waste handling, are $1.77 million per Defense Waste Processing Facility log. Each log is equal to 300 MTR-equivalents or about 268 typical aluminum-based foreign research reactor spent nuclear fuel elements. The 17,800 aluminum-based elements in the proposed foreign research reactor spent nuclear fuel program equate to about 21,400 MTR-equivalents, including the 85 French RHF elements at 20 MTR-equivalents per element, but excluding target material. This generates 72 Defense Waste Processing Facility logs. Four Defense Waste Processing Facility logs are inserted into one waste package canister (i.e., 18 canisters of glass logs for the alternative). Each canister has an estimated cost of $480,000. Total discounted costs to prepare the high-level waste for geologic disposal are about $65 million. Disposal costs are extra.

F.7.2.12 Transportation to the Repository

The canisters of foreign research reactor spent nuclear fuel or vitrified high-level waste must be shipped to a geologic repository for ultimate disposal. For cost estimation only, the approximate distances from the Idaho National Engineering Laboratory and the Savannah River Site to the candidate repository at Yucca Mountain, Nevada, were used. (No claim regarding the suitability of Yucca Mountain is implied by this assumption.) Using these distances, and assuming shipments by truck, the undiscounted and discounted total costs of repository shipping are estimated at $19 million and $3 million, respectively for all spent nuclear fuel and about $1 million (undiscounted) if the aluminum-based spent nuclear fuel is converted to vitrified high-level waste (EG&G, 1994b).

Shipping costs are sensitive to aluminum-based spent nuclear fuel canister loadings. At approximately 14.4 kg (31.7 lb) U-235 per canister on average, the foreign research reactor spent nuclear fuel program (excluding target material) requires about 602 canisters for aluminum-based spent nuclear fuel and 16 canisters for TRIGA spent nuclear fuel. Reductions in the canister loading translate directly into more shipments. Shipping costs are not highly sensitive to high-level waste disposal packaging. In the base case, converting all the aluminum-based foreign research reactor spent nuclear fuel to vitrified high-level waste generates about 18 canisters.

F.7.2.13 Disposal of Spent Nuclear Fuel

The base case method of disposing of foreign research reactor spent nuclear fuel is intact in poisoned canisters. Preliminary costs to dispose of intact foreign research reactor spent nuclear fuel were developed for DOE's Office of Civilian Radioactive Waste Management in November, 1995 (TRW, 1995). Table F-133 shows the canister loadings, number of canisters, and canister costs (not repository costs) for the internal criticality packaging strategy of 14.4 kg (31.7 lb) U-235 per disposal canister.

Table F-133 Internal Criticality Packaging Strategy: Number Required and Cost Detail (in Thousands of 1996 Dollars)

Fuel Type	U-235 Max kg/Element	Max (kg/package) U-235	Max Element/ Package	Package Cost ($1000)	Actual Element/ Package	Number Elements	Number Packages	Package Cost $1000
LE MTR	0.42	43	102	114	48	4,838	101	11,490
HE MTR	0.42	14.4	34	92	24	5,692	237	21,819
Dense MTR	0.84	14.4	17	92	24	296	12	1,134
LE Tube	0.40	43	108	114	48	1,149	24	2,729
HE Tube	0.40	14.4	36	114	48	2,928	61	6,954
LE Cluster	0.49	43	88	215[a]	48	1,695	35	7,557
HE Cluster	0.49	14.4	29	114[a]	24	1,097	46	5,211
RHF	9.20	14.4	1	57.1	1	86	86	4,911
LE TRIGA	0.038	43	1132	315[b]	1008	3,834	4	1,198
HE TRIGA	0.133	14.4	108	92[b]	96	1,106	12	1,060
Total						22,721	618	$64,0964

Source: TRW, 1995

[a] *Cost category shifted up 1 to (approximately) account for the fact that the longer length of the Cluster elements precludes their being stacked in three layers (so that the ratio is only 4 to 1).*

[b] *Cost category shifted down by 2 to account for the fact that the smaller width (diameter) of the TRIGA elements permits 16 to fit into the same cross-sectional area as PWR assembly in the commercial waste package.*

The discounted canister-related cost of the packaging strategy displayed in Table F-133 is $11 million. The cost to dispose of the canisters depends on the size of the canisters and the loading levels. An estimate for disposal of full-size (i.e., commercial-type) spent nuclear fuel canisters prepared by the Idaho National Engineering Laboratory equated to $1.8 million per canister in 1994$ in 1994 (Stroupe, 1995), including transportation to the repository. This translated into $2.07 million per canister in 1996$ in 1996, the baseline cost for this EIS. These canisters contained 120 MTR-equivalents of aluminum-based spent nuclear fuel and 500 TRIGA spent nuclear fuel elements.

For the much smaller canisters and lower loading levels shown in Table F-133, a total undiscounted disposal cost (excluding transportation) of $373 million is estimated (TRW, 1995). This translates into an implied charge per canister of approximately $100 thousand for canisters containing aluminum-based spent nuclear fuel and $150 thousand for canisters containing TRIGA spent nuclear fuel. Assuming that repository development costs (1/3 of total repository charges) are incurred from 1996 through 2029 and repository emplacement costs (2/3 of total repository charges) are incurred in 2030 through 2035, the discounted cost of the disposal program (excluding the canisters) is approximately $110 million. About 95 percent of this charge is for disposal of aluminum-based spent nuclear fuel. Discounted total costs for intact disposal of aluminum-based spent nuclear fuel and TRIGA spent nuclear fuel including canister are approximately $125 million.

Total program costs are highly sensitive to the timing of disposal. Accelerating disposal to the 2015 to 2020 time period (rather than 2030 to 2035) reduces undiscounted costs by $50 million but increases discounted costs by $50 million. The savings arise from fewer years of storage prior to repository loading. The discounted cost penalty arises because the large outyear costs for repository development and emplacement lose 15 years of discounting.

F.7.2.14 Disposal of Vitrified High-level Waste

High-level waste is vitrified in the Savannah River Site Defense Waste Processing Facility. The borosilicate glass logs are inserted into waste packages (i.e., metal canisters similar to that used to dispose of commercial spent nuclear fuel) and disposed geologically. The cost to dispose of each waste package is estimated at $1.61 million, including transportation to the repository. At four Defense Waste Processing Facility logs per waste package, the aluminum-based foreign research reactor spent nuclear fuel would generate about 18 waste packages. Discounted disposal costs would be about $10 million. The discounted cost to dispose of the 35 TRIGA spent nuclear fuel canisters at the same loading as described in Section F.7.2.13 is about $10 million. Discounted costs increase by $15 million and undiscounted costs decrease by $25 million due to accelerating repository disposal by 15 years.

F.7.2.15 Storage or Reprocessing Overseas (Management Alternative 2)

For the purpose of the cost analysis, the primary steps in Management Alternative 2 are as follows:

- Each country retains its spent nuclear fuel.
- The countries with commercial nuclear power reprocessing programs reprocess their spent nuclear fuel. The other countries dry-store their spent nuclear fuel.
- Spent nuclear fuel is geologically disposed in an unspecified manner at multiple sites.

Discounted costs for Management Alternative 2 are estimated (very roughly) at $1.25 billion. Costs for this alternative are highly speculative since there is no basis for estimating how most countries would manage their spent nuclear fuel individually or collectively or what types of facilities or approaches they would (or could) select. Of the 41 countries in the proposed foreign research reactor spent nuclear fuel program, 22 have no commercial nuclear power infrastructure to support either a storage or a reprocessing program. These 22, and most of the remaining 19, have no clear program for geologic disposal. Since no country inside or outside the proposed foreign research reactor spent nuclear fuel program has offered to store or dispose of the spent nuclear fuel from other countries, there is no obvious method by which most of the countries in the program could manage their spent nuclear fuel. The costs shown here assume substantial cost penalties from the establishment of up to 22 new spent nuclear fuel storage installations, including all supporting infrastructure.

Reprocessing at the United Kingdom Atomic Energy Authority's facility at Dounreay, Scotland is already an option for Euratom countries that can accept the return of the reprocessing waste. If the United Kingdom Atomic Energy Authority were to reprocess all the material in the foreign research reactor spent nuclear fuel program, including fuels for which it has no current commercial capability, direct costs would exceed $1 billion. Logistics would be highly problematic, however, since the United Kingdom Atomic Energy Authority would require at least 35 years to complete the task at its currently offered capacity. The limited number of other facilities that could reprocess commercial spent nuclear fuel, e.g., the French facility at Marcoule, have not made any commitments to do so. The technical and cost uncertainties associated with disposal of either spent nuclear fuel or high-level waste are entirely speculative but must be considered extremely high.

Overall, there is no basis for assuming that distributed management of the spent nuclear fuel and, in particular, distributed geologic disposal of the spent nuclear fuel or high-level waste, could be accomplished at a cost remotely resembling that of the United States or any other country with a large-scale commercial nuclear power infrastructure.

F.7.3 Interpreting the Minimum Program Costs

Table F-120 (Section F.7.1.2) showed the minimum discounted program costs for the five bounding scenarios. The table showed that for the discount rates appropriate for the U.K. and U.S. portions of the program, hybrid chemical separation/reprocessing of aluminum-based spent nuclear fuel in the United States and the United Kingdom (Management Alternative 3) was about as costly as chemical separation of aluminum-based spent nuclear fuel in the United States alone. Either of the chemical separation/reprocessing approaches was substantially less costly than storing and directly disposing of all the spent nuclear fuel in the United States.

In interpreting the minimum discounted program costs, note that important components of the costs of multiple alternatives are fixed or nearly fixed. Table F-134 shows this relationship. For example, shipping to the United States is the same whether all the spent nuclear fuel is stored or separated. This means that the differences between the costs for the key management function (i.e., storage and disposal or chemical separation and disposal) are substantially larger (in percentage terms) than the differences between the total costs of an implementation alternative. It also means that risks in the unique components of the various implementation alternatives will have an outsized impact on the relative costs of the alternatives.

Table F-134 shows that the undiscounted costs for Management Alternative 1 (storage) exceed $1.4 billion, excluding target material and all other cost and risk factors. The undiscounted costs for Management Alternative 1 (revised to incorporate chemical separation) are approximately $1 billion. Undiscounted costs for Management Alternative 3 are about $1.1 billion. A substantial portion of the cost premium for Management Alternative 3 is due to diseconomies of scale in using the Savannah River Site for two-thirds of the aluminum-based foreign research reactor spent nuclear fuel rather than all of the foreign research reactor spent nuclear fuel. Although not shown in Table F-134, use of a 4.9 percent discount rate for the European component of Management Alternative 3 would generate total costs that are indistinguishable from those under Management Alternative 1 (revised to incorporate chemical separation).

Table F-134 Composition of Minimum Program Costs for Spent Nuclear Fuel Management, 1996 Dollars

	Logistics & Program Management	*Shipping to United States*	*P-1 Operations at SRS*	*P-2 Operation at SRS, including Repository Fuels Qualification*	*P-1/P-2 Operations at INEL, Including Repository Fuels Qualification*	*Ship & Dispose Spent Nuclear Fuel*	*Reprocess Aluminum-Based Spent Nuclear Fuel (Net)*	*Stabilize, Ship & Dispose High-Level Waste*	*Dounreay (Including Blend Down, Net)*	*Total*
Management Alternative 1 (Storage, Dry)[a] Undiscounted	65	194	238	354	92	486	0	0	0	1428
Discounted	47	141	174	195	47	123	0	0	0	727
Management Alternative 1 revised to incorporate Chemical Separation[a] Undiscounted	65	194	190	55	92	13	231	150	0	989
Discounted	47	141	148	31	47	3	138	68	0	623
Management Alternative 1 revised to incorporate a New Technology[b] Undiscounted	65-70	+218	263	222-376	92	123-715	0	0	0	983-1,734
Discounted	47-52	158	191	129-241	47	54-244	0	0	0	626-933
Management Alternative 3[a] Undiscounted	44	124	136	37	92	13	113	100	417	1076
Discounted	32	90	108	21	47	3	73	45	263	682

[a] *No target material*

[b] *Includes target material*

Variations in the share of aluminum-based spent nuclear fuel that is stored/disposed in the United States versus separated/disposed in the United States shift the program costs within the boundary points established in Table F-134 for implementation alternatives to Management Alternative 1. This shift is non-linear, as summarized below:

- Spent Nuclear Fuel Repository Qualification - The proposed foreign research reactor spent nuclear fuel program would be responsible for the costs to repository-qualify an estimated three types of aluminum-based spent nuclear fuel. The discounted cost to characterize these three fuel types is approximately $25 million. (See Table F-123). If all the aluminum-based foreign research reactor spent nuclear fuel were separated, there would be no repository qualification and no charge to the program. Whether separation of less than all the aluminum-based spent nuclear fuel eliminates one or more fuel types from qualification requirements would depend on when the fuel was received, where each fuel type appeared on the prioritization for separation, and how long separation continues.

- Canyon Operating Costs - Canyon operating costs allocated to the foreign research reactor spent nuclear fuel program are at a minimum during the years when processing is incremental to processing under the Interim Management of Nuclear Materials EIS (1998 to 2002) and higher afterwards. Switching from incremental costing to average variable costing increases annual costs from as little as $1 million for 2,880 MTR-equivalents to about $32 million. Including the phase-down penalty (Section F.7.2.8) increases the cost by approximately $33 million per year. The timing of the switch from incremental costing to average variable costing (and thus the impact on the foreign research reactor spent nuclear fuel program) depends on decisions made under the Interim Management of Nuclear Materials EIS (DOE, 1995b) and a facilities utilization study underway at the Savannah River Site. The timing of any deferral penalty is subjective. It depends on whether other missions for the Canyons have been identified and whether plans to deinventory the Canyon used by the foreign research reactor spent nuclear fuel program have been developed. It is clear that Canyon operations costs allocable to the foreign research reactor spent nuclear fuel program per year or per MTR-equivalent would be much higher after 2002 than before 2002 but it is not certain how much higher or when they would become higher. This uncertainty prevents a linear estimation of separation costs according to the quantity of material processed. Section F.7.4 discusses this issue in more detail.

- Staging and Characterization Facility Capital Costs -- The Savannah River Site plans to construct a staging facility to transfer spent nuclear fuel from the existing wet basins to interim dry storage and ultimately to repository canisters. The unallocated discounted capital cost of this facility exceeds $150 million. There is no necessarily correct way to allocate the capital costs of this facility since it supports multiple components of multiple programs and is sized according to joint requirements of multiple programs. Section F.7.2.6 described the cost allocation approach used in this EIS. Approaches that could increase the costs allocated to the foreign research reactor spent nuclear fuel program are also plausible.

- Basin Operating Costs -- The Savannah River Site has estimated the costs to operate RBOF and L-Reactor disassembly basin over a roughly 10-year period at a round-the-clock operations level but has no generalized relationship that permits continuous variation in basin costs according to the number of elements received or stored. Costs depend on the timing of the receipts, the amount of characterization and canning, intra-site and inter-site transfer requirements, the variability in year-to-year staffing, and other factors.

Section F.7.4 outlines four additional groups of factors of significance in using the minimum program costs in Table F-120 as a decision basis for the program.

F.7.4 Interpreting the Other Cost Factors

Table F-120 showed the minimum discounted cost for the five bounding scenarios. The costs in Table F-120 include component contingencies but they do not include system risks, component and non-component risks, or the effects of discount rate changes.[14] Table F-121 showed these latter factors for the five scenarios. Detailed discussions are presented below. Real escalation is excluded from all costs in both tables.

F.7.4.1 Systems Integration and Logistics

The minimum program costs include the contingencies related to individual components of the program, e.g., shipping, basin operations, storage, transfers, and disposal. The minimum program costs do not include systems integration or logistics risks. The proposed foreign research reactor spent nuclear fuel program involves 41 foreign countries (a majority of which have no commercial nuclear power program), dozens of foreign ports, 13 years of receipts, up to 10 domestic ports, as many as 250 cross-country spent nuclear fuel shipments, at least two management sites, and developmental technologies (especially repository disposal technologies). Substantial systems integration bottlenecks could arise in many technical areas, e.g., insufficient casks to ship at the required rate or at the estimated loadings; vulnerability-related shutdowns at existing facilities; requirements for on-site canning prior to cask loading; unplanned requirements for dry storage characterization or conditioning; unexpected facilities requirements for meeting the repository waste acceptance criteria; delays in repository acceptance; and so forth, including normal project (not component) contingencies.

Substantial bottlenecks could also arise in many procedural areas, e.g., incompatibilities with Naval programs at the Idaho National Engineering Laboratory; requirements for on-site inspections by the International Atomic Energy Agency; constraints on shipments, duration of shipments, shipment routes, or quantities of materials shipped pursuant to agreements with the states, and so forth. Because the list of technical and procedural issues that could delay and complicate the program is both long and highly plausible, it is realistic to expect costs to increase above the component-level minimums that make up Table F-120. This risk is estimated at 10 to 15 percent of minimum discounted program costs.

F.7.4.2 Program Component Risks

Several key components of the foreign research reactor spent nuclear fuel program are uncertain. This section discusses the most important probability-adjusted uncertainties (risks).

- ***The method of disposal of spent nuclear fuel***- The base case assumption is that aluminum-based HEU spent nuclear fuel and HEU TRIGA spent nuclear fuel can be loaded into poisoned canisters and disposed at the equivalent of 14.4 kg (31.7 lb) U-235 per canister. This packing density could be unacceptable to the repository program. Processing the uranium into an isotopically neutral mass (1 percent U-235) would require construction of a new melt-and-dilute facility. Construction and operation of this facility

14 Contingencies refer to costs that are certain to occur based on historical experience with programs of similar maturity. These costs are grouped under the term "contingency" because they cannot be line-itemized. Uncertainties refer to changes in the costs of individual components or the overall program that might occur due to unknown changes in regulations, technical conditions, operational status, etc. They are assigned a probability based on their likelihood. Thus, contingencies will occur--they just cannot be line-itemized; uncertainties may occur-- they are adjusted for their probability of occurrence and expressed as risks.

could add $100 million or more to the cost of spent nuclear fuel disposal. Processing the spent nuclear fuel to avoid severe mass limitations on disposal is considered a high probability event.

- ***The adequacy of limited characterization of the spent nuclear fuel*** - There is technical uncertainty about the requirements for characterizing and conditioning the spent nuclear fuel before storing it. At the Savannah River Site, the characterization stage consists of checking the history of the spent nuclear fuel and its paperwork (documentation), visual inspection, gamma scanning (to verify the presence and amount of fissile material), and a leak detection test ("sipping") to determine if any fission products are escaping from the spent nuclear fuel elements. Canning would be limited to degraded elements only. If more extensive characterization and canning is required, new hot cells may be required. Allocable discounted costs to add and operate a hot cell at the staging facility are on the order of $100 million. The requirement for additional characterization and conditioning is a moderately probable event.

- ***Bottlenecks at the Defense Waste Processing Facility*** - Complete separation of aluminum-based spent nuclear fuel at the Savannah River Site generates about 72 Defense Waste Processing Facility logs at a cost of $1.77 million per log. The Savannah River Site estimates that for capital costs of about $100 million and operating costs of about $40 million per year, it could remove bottlenecks at the Defense Waste Processing Facility such that the cost would decline to $1.0 million per year. For the foreign research reactor spent nuclear fuel program, the allocated cost of the capital and operating requirements to relieve the bottleneck is a few million dollars. The discounted savings would be in the range of $50 million. The likelihood that the foreign research reactor spent nuclear fuel program would realize these savings is low to moderate.

- ***Failure to commercially sell the recovered uranium*** - The Savannah River Site might not be allowed to blend-down the recovered HEU for sale as power reactor fuel. DOE, for example, could choose to safeguard the HEU and isolate its chemical separation operations from the commercial power market. This would cost the foreign research reactor spent nuclear fuel program an additional $70 million. The likelihood that the foreign research reactor spent nuclear fuel program would fail to recover this value is low.

F.7.4.3 Non-Program Risks

The key non-program risk is that the cost of repository disposal increases across the board due to a change in scope (not due to escalation within the existing scope). The repository cost allocation used in this EIS assumes no monitored retrievable storage and one geologic repository. If either of these assumptions is incorrect, the cost of the repository component of the program would increase by about 20 percent. If both are incorrect, the cost of the repository component of the program would increase by about 40 percent. These increases translate into cost increases for geologic disposal of intact foreign research reactor spent nuclear fuel of about 5 to 10 percent. The cost of the chemical separation alternative (including disposal of TRIGA spent nuclear fuel) would increase by about 1 to 2 percent.

Cost escalation in the base repository program would also increase the allocated costs for the foreign research reactor spent nuclear fuel program. This type of cost escalation is highly speculative but could be in the tens of millions of dollars for the storage alternatives. Escalation is treated separately from other cost risks.

A second non-program risk is that one or more of the EISs that relate to materials management and facilities use at the Savannah River Site or the Idaho National Engineering Laboratory (besides the foreign research reactor spent nuclear fuel EIS) leads to legal or regulatory action that delays all site activities and throws the foreign research reactor spent nuclear fuel program off-schedule or out of the planned facilities.

F.7.4.4 Discount Rates

This EIS uses the real discount rate specified by the Office of Management and Budget for long-term government projects evaluated in the year ending February 1996 (OMB, 1995). The specified rate, 4.9 percent, is historically high. It compares to Office of Management and Budget rates of 3.8 percent, 4.5 percent, and 2.9 percent for the years ending in February of 1993, 1994, and 1995, respectively (OMB 1992; OMB, 1993; OMB, 1994). It also compares to measured real, long-term government interest rates of 3.2 percent, 2.9 percent, 4.1 percent, and 3.4 percent (through 1995 quarter 2), respectively for the years 1992, 1993, 1994, and 1995 (FRB Cleveland, 1995). Finally, it compares to a Congressional Budget Office estimate of 2 percent for government projects independent of the period and duration (Hartman, 1990).

Unlike the United States, the United Kingdom issues some debt instruments that are the equivalent of inflation-adjusted treasury securities. In recent years, these have yielded between 2 and 5 percent. The rate as of mid January, 1996 was approximately 3.6 percent. The United Kingdom is also currently considering the required discount rate (i.e., real rate of return) on trust funds to provide for decommissioning commercial nuclear power plants. Although no decision has been reached, the government supports a 6 percent rate while the United Kingdom nuclear utilities support a 2 percent rate.

The appropriate discount rate for the analysis is the risk-free rate at which funds received today can be invested to cover future expenses. Since receipt of the revenues precede expenditures, a conservative rate is low. This is the reverse of the more common situation where a high rate is used to discount future receipts compared to current expenses. Moreover, where fixed and certain revenues precede variable and uncertain expenses, the need for a conservative (i.e., low) discount rate is even greater. At a 3 percent discount rate, the discounted cost of Management Alternative 1 (storage) increases by $175 million (to $900 million). The cost of Management Alternative 1 (revised to incorporate chemical separation) increases by $120 million. The effect on the storage alternative is much greater because the high out-year costs for repository canisters and repository emplacement are much more prominent at the lower discount rate.

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